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AFWAL-TR-82-2058

AD A119999

TURBINE ENGINE FAULT DETECTION AND ISOLATION PROGRAM
VOLUME II - Maintenance Model Development

SYSTEMS CONTROL TECHNOLOGY, INC.
1801 PAGE MILL ROAD
PALO ALTO, CA 94303

AUGUST 1982

FINAL REPORT FOR PERIOD 15 AUGUST 1979 - 30 NOVEMBER 1981

AERO PROPULSION LABORATORY
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REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER AFWAL-TR-82-2058, Volume II	2. GOVT ACCESSION NO. AD-A119999	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) TURBINE ENGINE FAULT DETECTION AND ISOLATION PROGRAM : Maintenance Model Development		5. TYPE OF REPORT & PERIOD COVERED FINAL REPORT August 1979 - November 1981
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) Dr. Randall Fleming, Dr. Ronald DeHoff		8. CONTRACT OR GRANT NUMBER(s) F33615-78-C-2062
9. PERFORMING ORGANIZATION NAME AND ADDRESS SYSTEMS CONTROL TECHNOLOGY, INC. 1801 Page Mill Road Palo Alto, CA 94303		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS 30661327
11. CONTROLLING OFFICE NAME AND ADDRESS AERO PROPULSION LABORATORY (AFWAL/POTC) Air Force Wright Aeronautical Laboratories Wright-Patterson AFB, OH 45433		12. REPORT DATE August 1982
		13. NUMBER OF PAGES 77
14. MONITORING AGENCY NAME & ADDRESS(if different from Controlling Office)		15. SECURITY CLASS. (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This report consists of two volumes: Volume II - Maintenance Model Development Report

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

IECMS, TEMS, EDS, MIMS, ECM, TEFDI, TF34, TF41, F100

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

Maintenance decision analysis models for evaluation of the TF34 maintenance process, both with and without the Turbine Engine Monitoring System (TEMS), are formulated. These models form the foundation for the U.S. Air Force to establish techniques for determining optimal policy for troubleshooting and maintenance on its aircraft engines using decision analysis methods. Technical background is provided and models presented. Model structure and parametes, as well as input and output, are treated.

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20. ABSTRACT (Continued)

A preliminary plan for model evaluation is given, including methods for data collection, model evaluation criteria, as well as solution techniques and algorithms for the actual model evaluation. Conclusions are drawn and directions for future activity are suggested.

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I. INTRODUCTION

This report presents the results of Systems Control Technology, Inc. (SCT)'s preliminary study of maintenance decision models for evaluation of the TF34 maintenance process both with and without the Turbine Engine Monitoring System (TEMS). The order of presentation will be as follows: Section II presents a summary of relevant technical background material in decision analysis methods and in the TF34 maintenance process. In Section III, the models developed by SCT under this study are discussed. Model structure and parameters as well as input and output are treated. Section IV outlines the preliminary plan for model evaluation. Included in this plan will be methods for data collection, model evaluation criteria, as well as solution techniques and algorithms for the actual model evaluation. Section V solves a small test case while Section VI draws conclusions and makes recommendations as to study areas and activities for future work in this area. Section VII presents reformulated versions of the models of Section III in order to emphasize decision points and to point out places where human or judgemental factors enter into the model.

II. BACKGROUND

This section presents an overview of technical background material useful in the development of the TF34 maintenance models (Section III) and an plan for their evaluation (Section IV). The material falls into two general categories: decision analysis techniques and the TF34 maintenance process. Section 2.1 treats the former subject while Section 2.2 treats the latter.

2.1 DECISION ANALYSIS TECHNIQUES

Decision analysis is a discipline within management science which seeks to apply logical, mathematical and scientific procedures to the decision problems of top management. Such problems are characterized by the following: uniqueness, importance, uncertainty, long run implications and complex preferences. Decision analysis provides a logical framework for balancing all these considerations while permitting mathematical modeling of the decision process, computational implementation of the model, and quantitative evaluation of results.

Much literature exists on the subject of decision analysis. Only a brief overview of some of the concepts and subject areas to which it has been applied will be discussed here. A more extensive introductory discussion can be found in [1] and the references listed there.

Figure 2.1 illustrates a general framework into which all decision analysis modeling efforts can be classified. Given a set of "a priori" information or data, there are five basic steps: model development, model simplification, model evaluation, cost benefit analysis and collection of new information. These steps form a cycle allowing for continual update of the model results as well as the model itself as new information becomes available. Following model evaluation, a

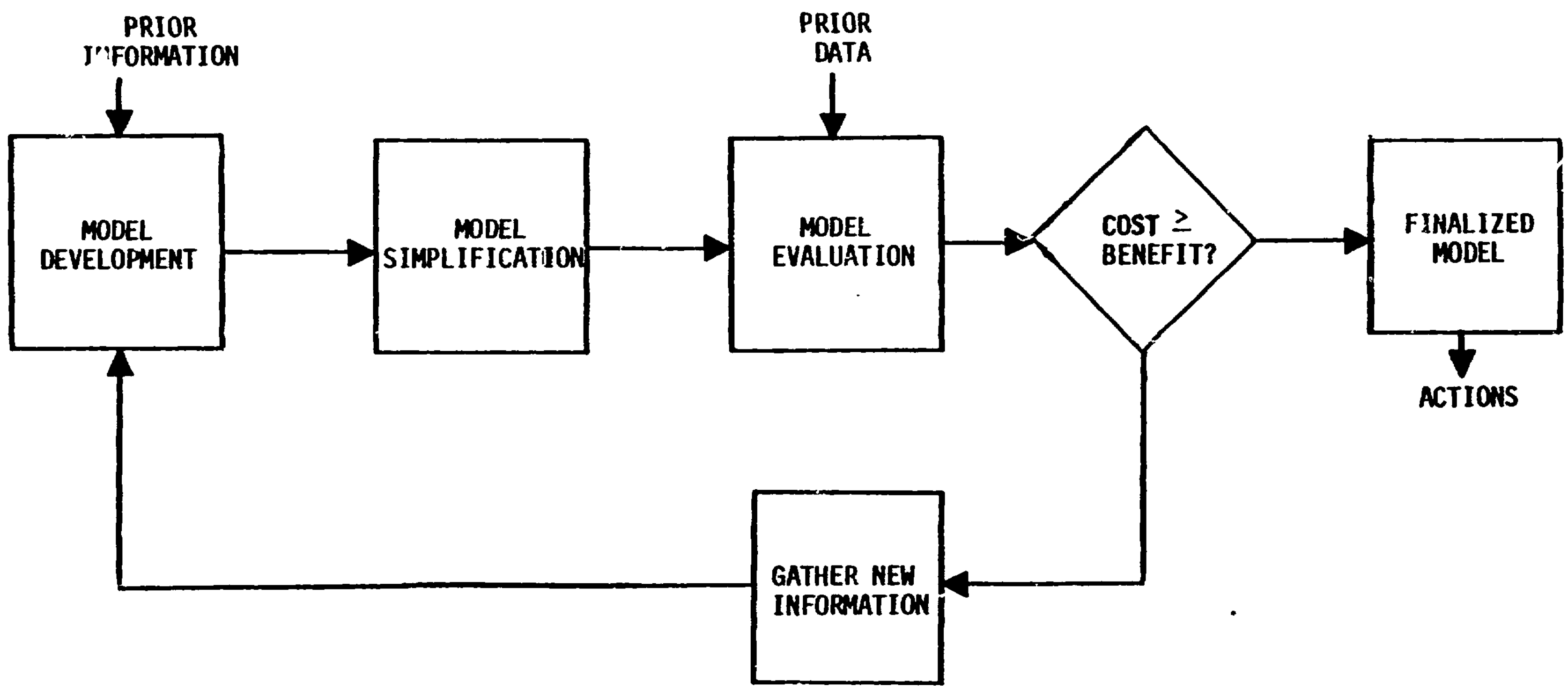


Figure 2.1 Decision Analysis Cycle

cost benefit analysis examines the trade-off between the value of acquiring new or perfect informaton and the cost of acquisition. If the cost exceeds the value, the decision analysis stops, conclusions are drawn and appropriate actions taken.

The model development phase involves the creation of a structural model of the decision process under study as well as value and time preference models which represent the decision maker's opinion as to the worth of the various possible outcomes to the structural decision model.

The structural model often appears as a decision tree. A decision tree is composed of decision variables (under control of decision-maker), state variables (random, under control of "nature"), actions (results of decisions) and outcomes (results of chance or state variables). Figure 2.2 provides an example tree. Decision variables are represented by squares, state variables by circles, and outcomes by triangles.

The size of the tree is bounded by the number of alternative actions for each decision variable and the number of possible chance outcomes of each state variable. The tips of the tree branches represent outcomes of the entire decision process, i.e. whatever it is the decision-maker would like to know in retrospect to determine how the problem came out.

The value model development consists of specification of the costs (measured by decision-maker's objectives) of making an action and the value (to the decision-maker) of each overall outcome in the structural model.

The time preference model simply represents the decision-maker's time preference for various outcomes of the structural model. Good outcomes are preferred sooner and bad ones later.

Once these three models have been developed, the worth to the decision-maker of any possible outcome (fixing all the decision and state variables to a single value can be determined. The model simplification phase of decision analysis

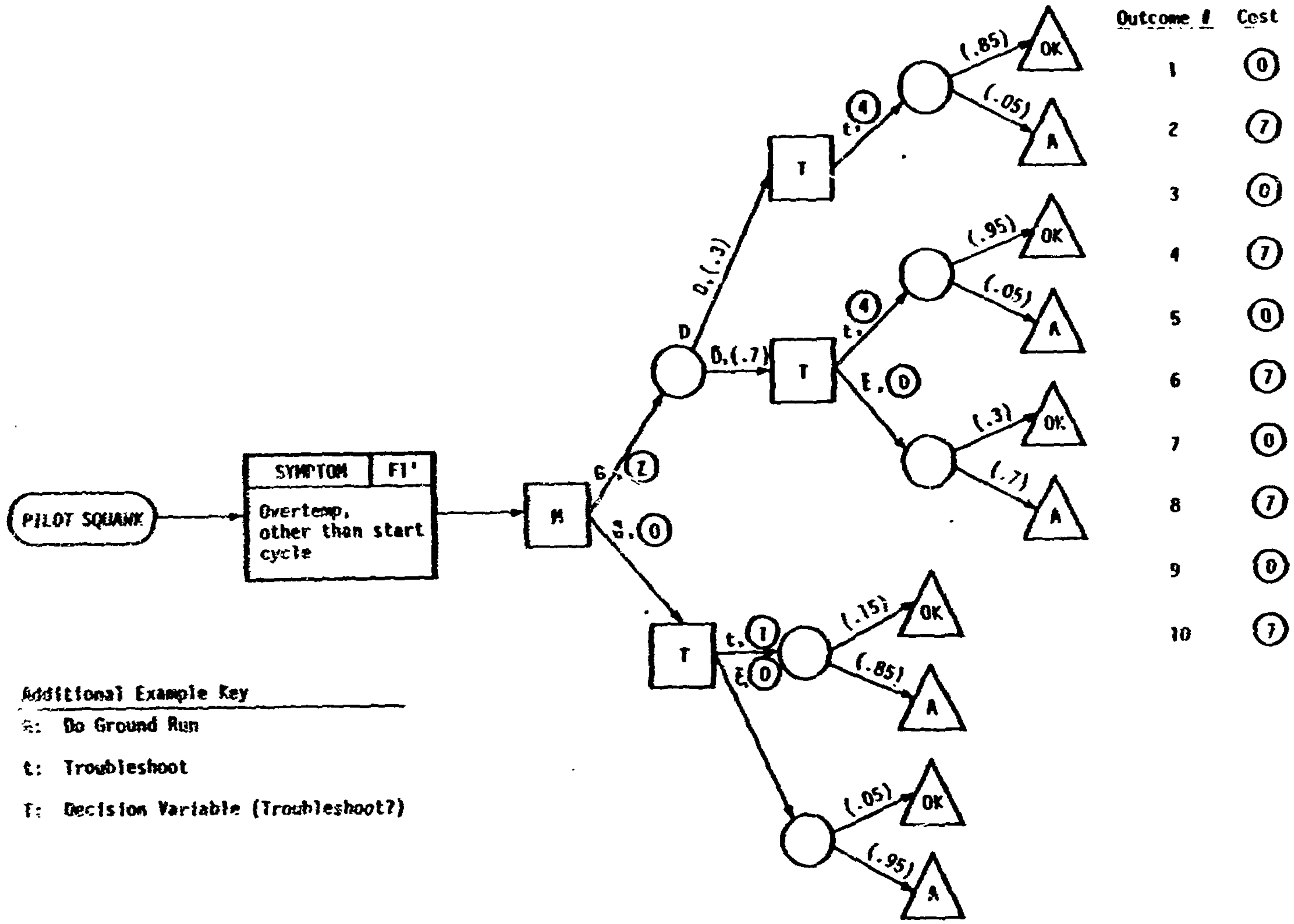


Figure 2.2 Example From TF 34 Maintenance (Without TEMS)

involves performing a sensitivity analysis, i.e. observing how changes in various decision and state variables affect worth. Variables which have little to no effect on the overall worth are dropped from the model, simplifying the problem.

The model evaluation phase involves two steps. The first is the specification of remaining inputs to the problem, the probability distributions of state variable outcomes and the risk preference of the decision-maker. The second is the solution of the decision problem given these inputs and validation of results. Optimal action(s) and their worth to the decision-maker are computed as well as sensitivity of the results to various input quantities. Low sensitivity establishes validity of the result. Some standard mathematical programming solution techniques and algorithms can be found in Ref. 2.

Due to the randomness inherent in the state variables, a decision maker's risk preference (usually expressed as a utility function) is needed to uniquely determine the best policy. An "EMV" decision-maker is one who acts on the basis of percentages or mean values. In contrast, a risk-averse person is one who is willing to trade-off some of his expected income for protection against bad outcomes. For the decision-maker who is confronted with multi-objective decisions, multi-attribute utility and value theoretic methods are available [3].

Following the model evaluation phase, there are two possible decisions: act on the basis of current information and model results or gather more information and run through the decision analysis cycle again. A cost-benefit analysis is done to determine whether or not the cost of gathering new information and delaying a decision to act exceeds the value of that information in reducing the uncertainty in the state variables, thus producing more certain conclusions. If costs are greater, then the optimal action is to stop.

Although each decision analysis is unique, the underlying techniques involved in performing the previously mentioned phases

are application independent. These techniques have been applied profusely in a variety of fields from health care (see Ref. 4) to systems engineering to medicine (see Refs. 5 and 6). They have not as yet been used extensively in the logistics field, an application which is treated in the remainder of this report.

This subsection concludes with a short discussion of the feasibility of utilizing decision analysis as a tool in the first place. The answer to this question is that it depends on the problem and more specifically the objectives or goals of the decision-maker. Some objectives naturally lend themselves to mathematical expression (quantifiable) while others do not (nonquantifiable). Prime examples of the latter in TF34 maintenance include such criteria as acceptance of system outputs on all user levels or improved understanding of the engine by maintenance personnel. It can be said, however, that the flexibility of decision analysis techniques and their scope of applicability exceeds that of most other operations research techniques and so chances are good that at least a significant portion of any engineering decision problem will fall under this scope.

Advantages and disadvantages of decision analysis are listed in Table 2.1.

2.2 THE TF34 MAINTENANCE PROCESS

This section discusses the Air Force TF34 engine maintenance process. First, an overview of the maintenance organization is given followed by a discussion of the maintenance decision process. Finally the management of engine information through use of CEMS IV is described.

The TF34 engine is employed by the Tactical Air Command (TAC) in A10 aircraft. The typical TAC mission requires rapid deployment and immediate fighting capability of aircraft. Thus TAC uses a production oriented maintenance organization (POMO)

Table 2.1

Advantages/Disadvantages

- ADVANTAGES
  - EXAMPLE PROBLEM GLOBALLY
  - STIMULATES CONSIDERATION OF VIABLE OPTIONS
  - ENHANCES COMMUNICATION
  - ESTABLISHES DATA COLLECTION GUIDELINES
  - QUANTIFIES UTILITIES/PREFERENCES
  - PROVIDES CAPABILITY FOR UPDATING ANALYSIS
- DISADVANTAGES
  - LACK OF POLITICAL CONSIDERATIONS
  - LACK OF ENGINEERING JUDGEMENT
  - ARTICULATION SLOWS THOUGHT PROCESS
  - INCOMPLETE "COST" OBJECTIVE FUNCTIONS

oriented towards maintaining deployable, independent squadron-size fighting units capable of supporting high sortie rates and surviving in a forward location. Air Force regulation 66-5 [7] describes the POMO, its maintenance management policy and procedures.

Unlike the traditional centralized maintenance concept (AFM-66-1 [8]), the POMO decentralizes decision-making. Rather than organizing people into specialized tasks, personnel and equipment are organized into sortie producing elements. Table 2.2 summarizes the major differences in AFM 66-1 and AFR 66-5.

Figure 2.3 shows how POMO operates. The aircraft generation squadron (AGS) has the responsibility to maintain or generate aircraft to support the unit direct sortie requirements. These are the same whether in peace or in combat. The AGS handles flightline or on-aircraft maintenance. The component repair squadron (CRS) and equipment maintenance squadron (EMS) perform off-aircraft maintenance and in-shop work. The activities of the AGS, CRS, and EMS are coordinated by a job control.

Figure 2.4 summarizes the engine maintenance decision process without the Turbine Engine Monitoring System (TEMS). Maintenance is done in one of three locations: on flightline, at JEIM (jet engine intermediate maintenance) or base, or at depot. Flightline maintenance is done on aircraft (by the AGS). If troubleshooting on the line indicates a problem requiring engine removal, the engine is then either repaired at base or sent to depot, depending on the type of maintenance required. Repaired engines become part of a pool of spares which are installed in aircraft as needed.

Figure 2.5 illustrates in more detail that portion of the unscheduled engine maintenance decision process influenced by TEMS. TEMS is useful in assisting engine problem symptom detection as well as flightline troubleshooting. The optimal integration of the TEMS into the TF34 maintenance procedure has

Table 2.2

AFR 66-5 POMO

MAJOR DIFFERENCES

AFM 66-1	AFR 66-5
● SPECIALIZATION	● PRODUCTION TASKS
● CENTRALIZATION	● DECENTRALIZATION
● WING SIZE EFFICIENT	● SQUADRON SIZE EFFICIENT
● ALL MAJCOM COMPROMISE	● TAILORED FOR TAF
● LIMITED UTILIZATION OF PEOPLE	● FLEXIBLE UTILIZATION
● COMBAT ORGANIZATION DIFFERS FROM PEACE	● COMBAT AND PEACE SAME

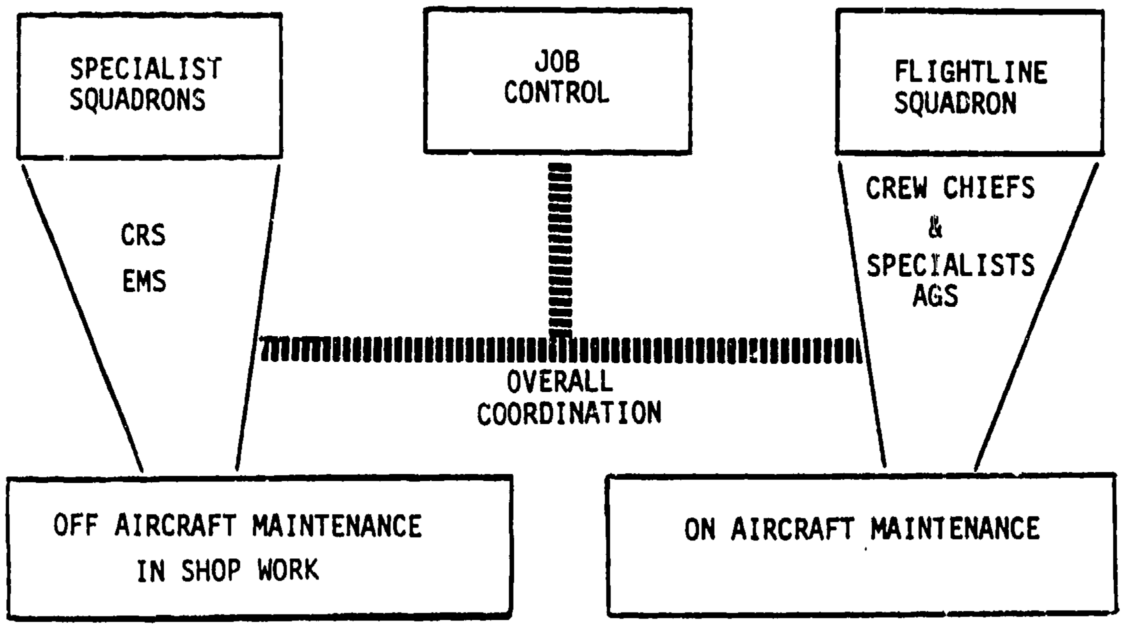


Figure 2.3 AFR 66-5--(POMO)

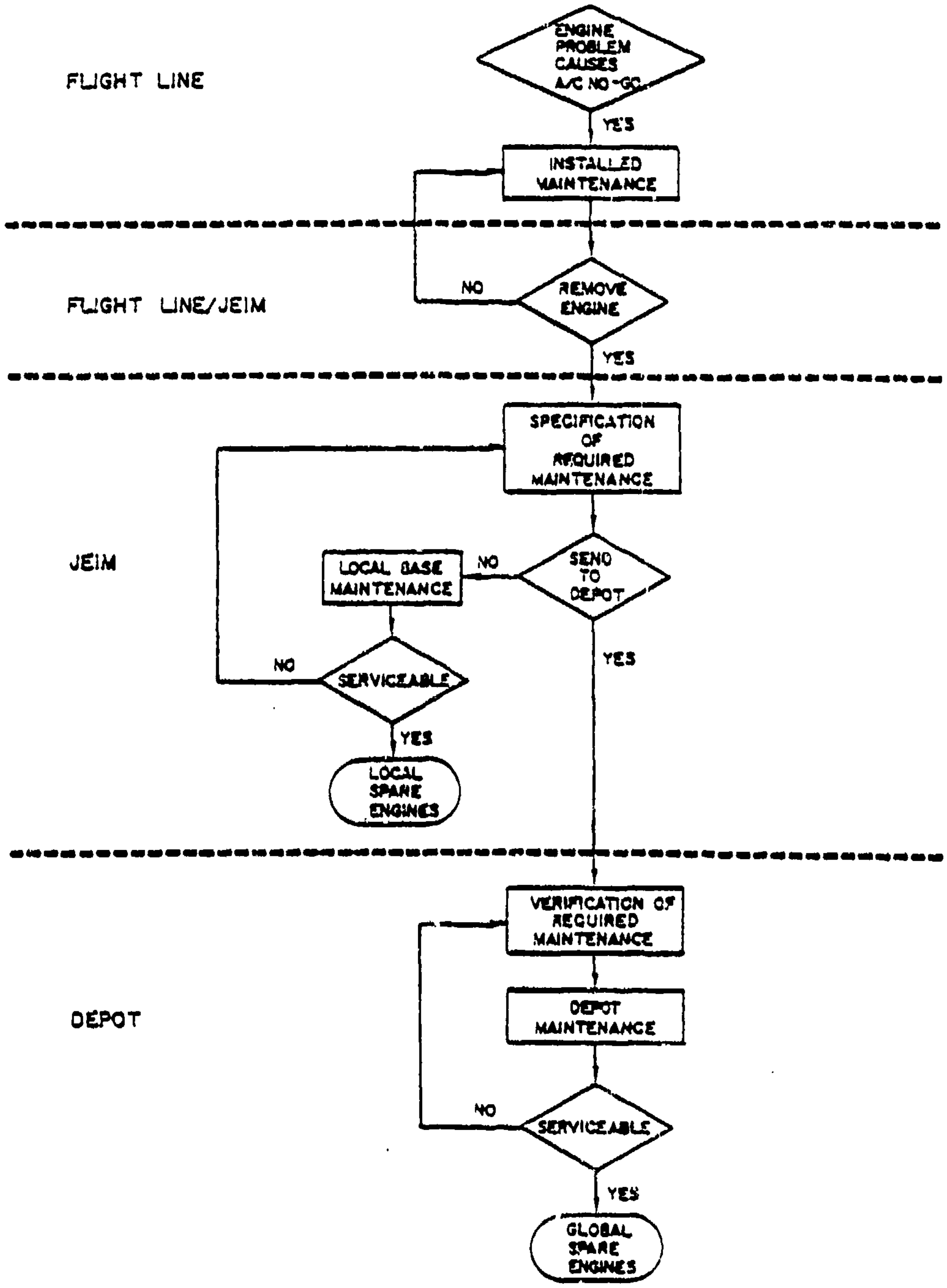


Figure 2.4 Maintenance Decision Processes

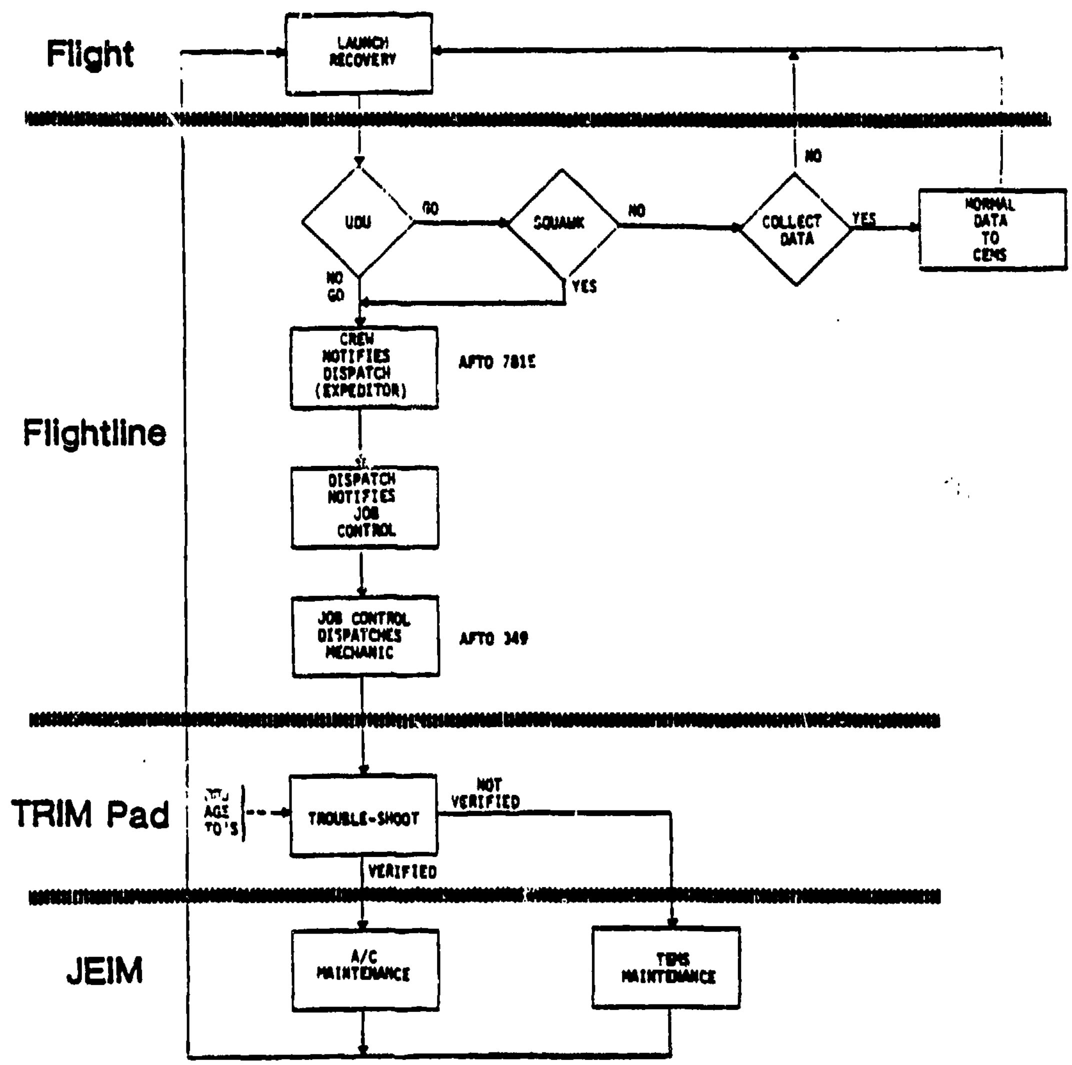


Figure 2.5 AIO/TEMS Maintenance Scenario

not yet been determined but can be as part of the maintenance decision analysis and improvement program (Section VI).

The general procedure is as follows: there are ACFT (Aircraft) NO GO and TEMS NO GO indicators located in the forward wheel well of each TEMS equipped aircraft. If both of these are "green", then the flight data is collected and the aircraft turned around in accordance with normal procedures. If either the ACFT NO GO indicator is "not green" or the pilot or crew chief squawks, the crew notifies dispatch through an AFTO 781E form. Dispatch then notifies job control which dispatches a mechanic (AFTO 349) to troubleshoot the detected symptom. Troubleshooting is then done by the mechanic on the basis of information received from AFTO's 781 and 349, AGE (aerospace ground equipment) and the TEMS DDU display. If a problem is verified, engine maintenance is done - if not, troubleshooting is done on the TEMS. If maintenance requires engine removal, repair then proceeds just as without TEMS in Figure 2.4. A TEMS NO GO "not green" indicator will not cause immediate scrapping of a mission, however repair or replacement of TEMS should be done as soon as possible.

The final portion of this section describes the management of engine information through CEMS IV. Figure 2.6 summarizes this flow of information. CEMS information will be stored both at base and at a central data bank (CDB). At base CEMS will support intermediate shop, integrate base data sources, and condense data for analysis, as well as transfer to the CDB where users will be seeking less detailed information. Organizations such as ALC, AFLC HQ, and MAJCOM HQ will have access to the CDB. At the CDB level, CEMS information will support fleet visibility for readiness, depot maintenance as well as CIP and maintenance analysis.

CEMS IV capabilities include the storage of all engine condition information necessary to support the repair cycle monitor (RCM) process, the ability to integrate such information

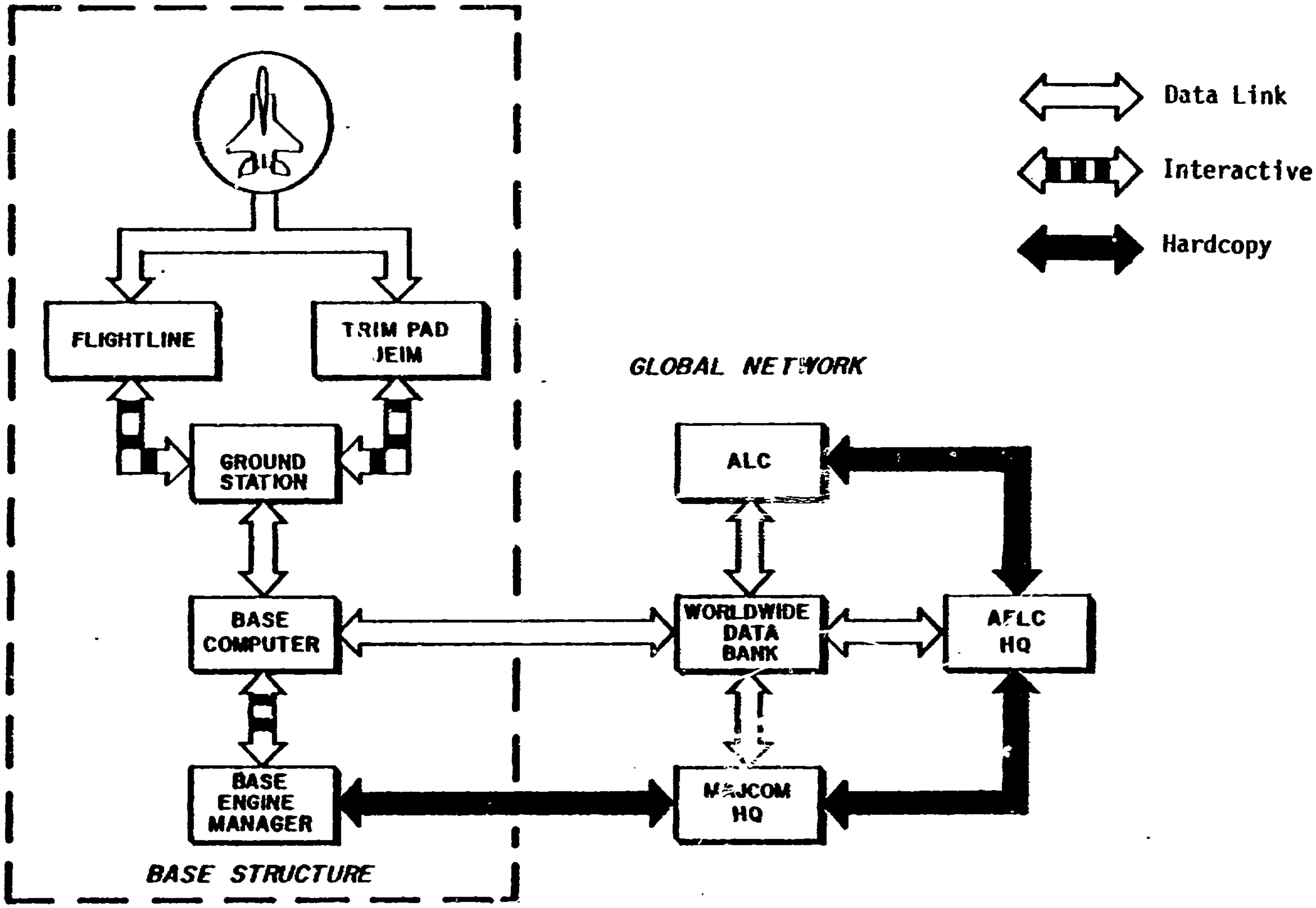


Figure 2.6 Management of Engine Information

into useful and timely data elements, and the ability to access such data at appropriate levels and in usable formats. Engine condition information includes operating time, temperature and cycle data, maintenance actions and oil analysis results among others. Such raw data can be integrated into more useful forms for use in diagnostics, tracking critical components, forecasting engine health, scheduling preventative maintenance, or generation of input parameters to maintenance decision models.

A CEMS IV prototype program is currently in progress. Its goals are to implement a prototype that supports engine management functions at the base, MAJCOM and ALC levels, providing a controlled environment in which to test, evaluate and refine the software system. Other goals are to integrate data sources and structures from the oil analysis program (OAP), maintenance data collection system (MDC), the maintenance management information and control system (MMICS) and the TF34 TEMS.

III. THE MAINTENANCE DECISION MODELS

This section describes the block diagram decision models developed by SCT for purposes of modeling the TF34 maintenance process. There are two types of diagrams: high level decision models and detailed maintenance procedure models. Output from the detailed models feeds into the high level models as shown in Figure 3.1, supplying the input troubleshooting procedure costs. Section 3.1 discusses the high level models while Section 3.2 treats the detailed maintenance models.

Before getting into the model details, a few points concerning assumptions should be made. Only maintenance influenced by TEMS is considered, i.e. unscheduled maintenance of aircraft which have been grounded due to symptoms detectable by TEMS (most symptoms). Inclusion of other symptoms or types of maintenance within this structure would be a trivial exercise if necessary at a later time. Engine troubleshooting and maintenance procedures without TEMS are assumed to be as stated in TO 2J-TF34-6 (see Ref. 9, Ch. 10) while those with TEMS are assumed to be those in the USAF A-10 TEMS Training Manual [10]. TEMS troubleshooting is assumed to be done as specified in Ref. 11.

3.1 HIGH-LEVEL BLOCK DIAGRAMS

The high-level block diagrams are decision analysis models for the TF34 maintenance process with and without TEMS. Figures 3.2 and 3.3 exhibit the models respectively without and with TEMS. For purposes of optimal visual display, each of Figures 3.2 and 3.3 appear over three pages. The keys to or verbal descriptions of model notation appear in Tables 3.1 and 3.2.

There are eleven symptoms detectable by TEMS (on DDU display window F) plus the possibility of no symptoms being detected.

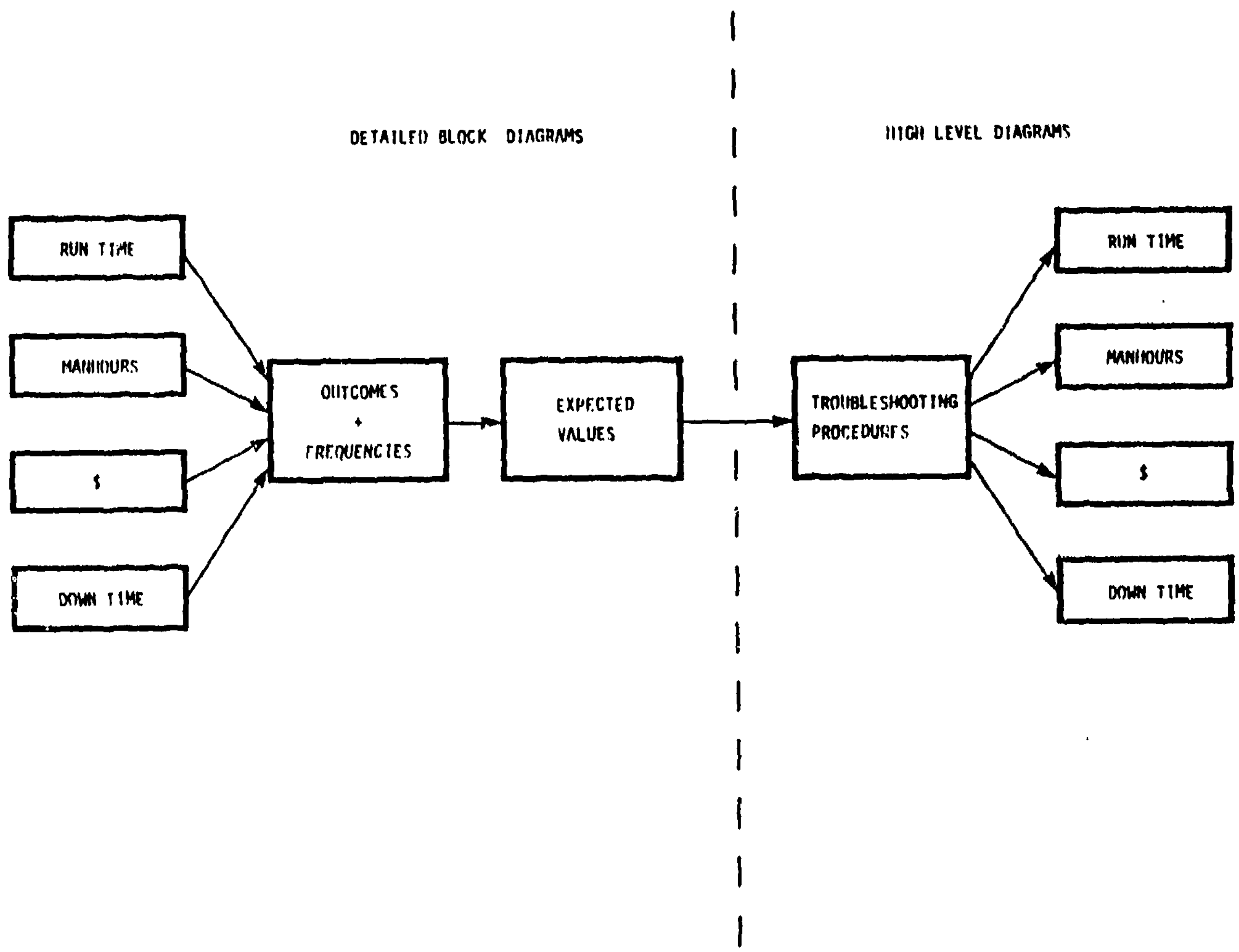


Figure 3.1 Detailed High Level Diagram Interface

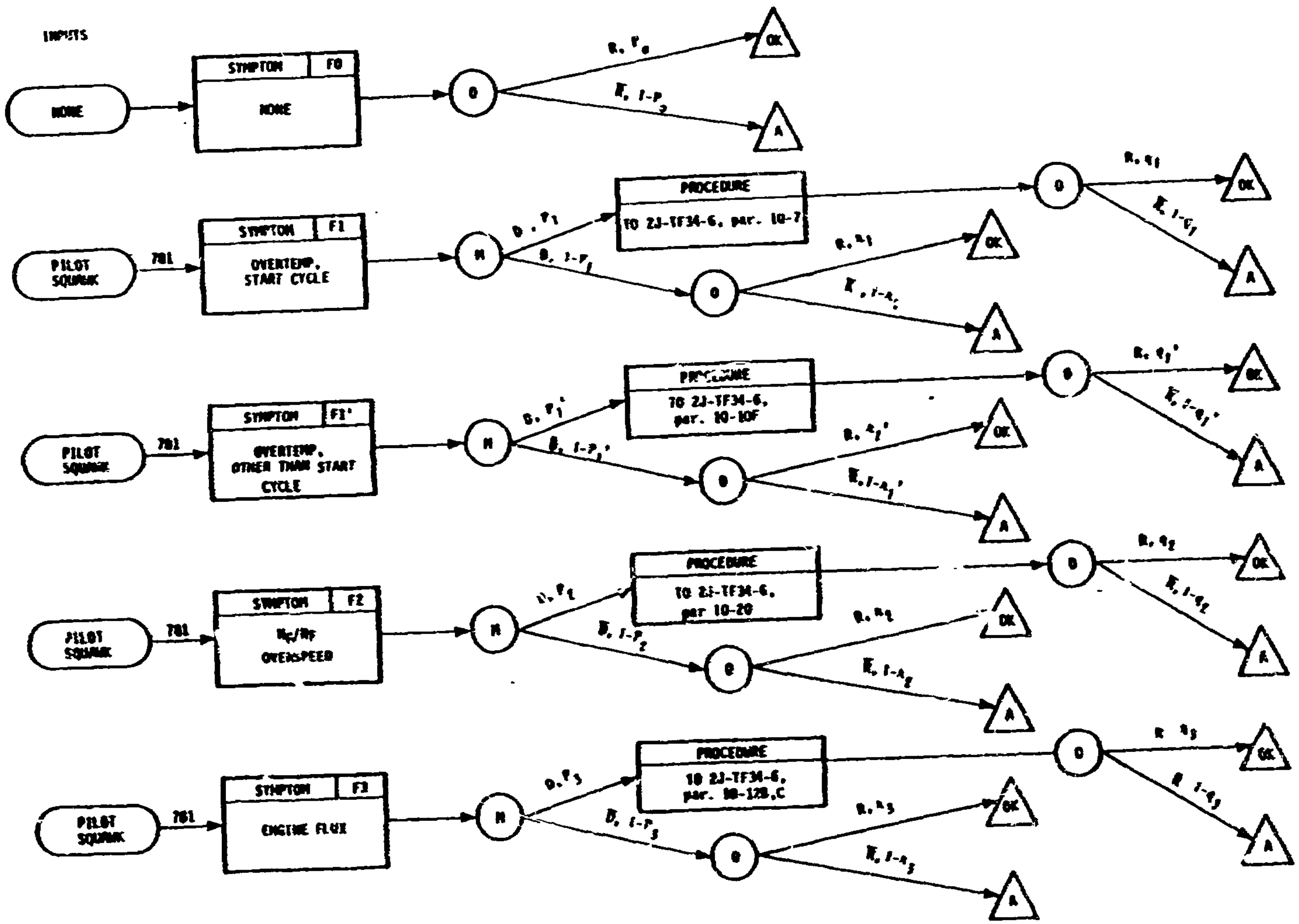
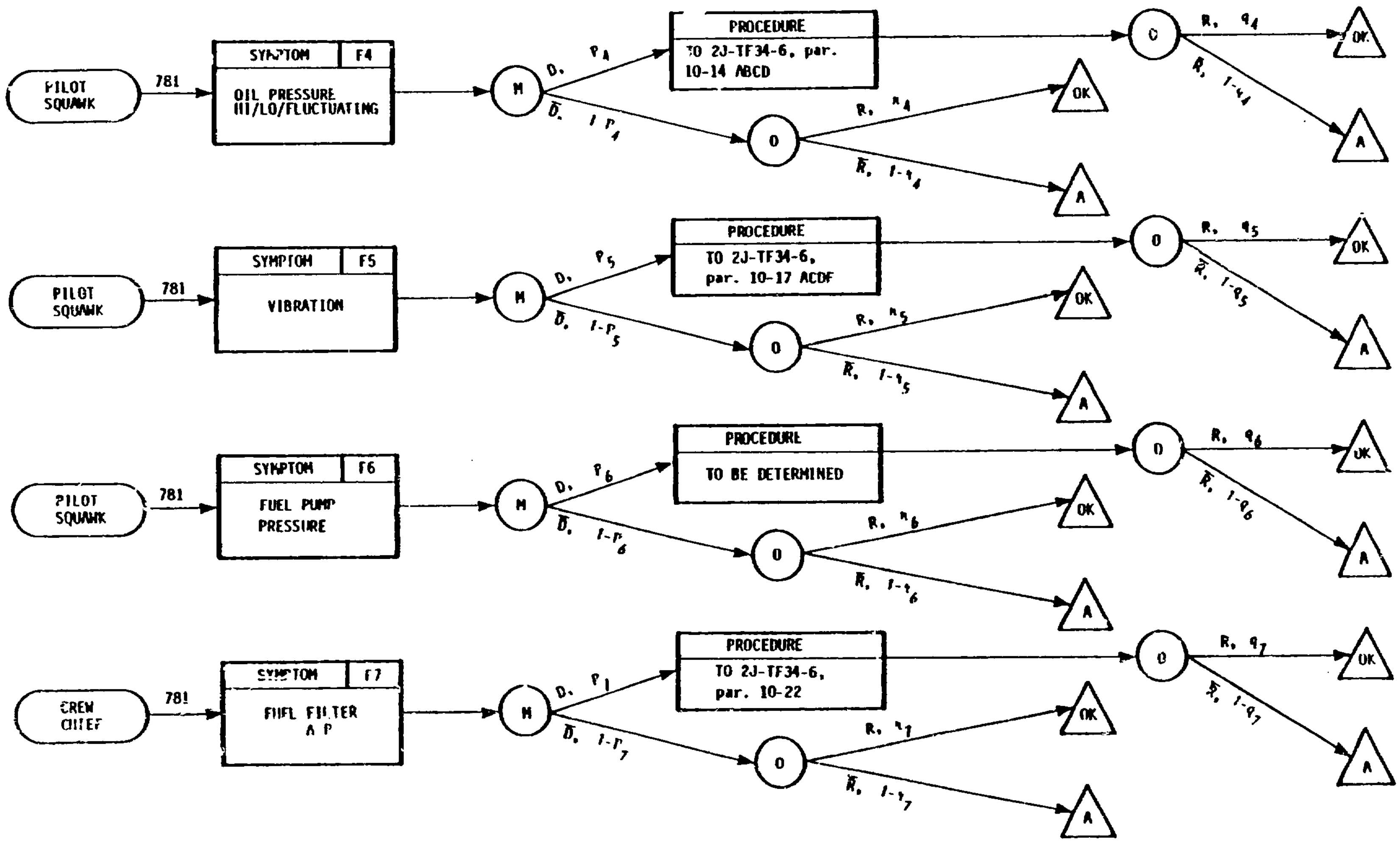


Figure 3.2 High Level Maintenance Flow - TF 34 Engine Without TEMS



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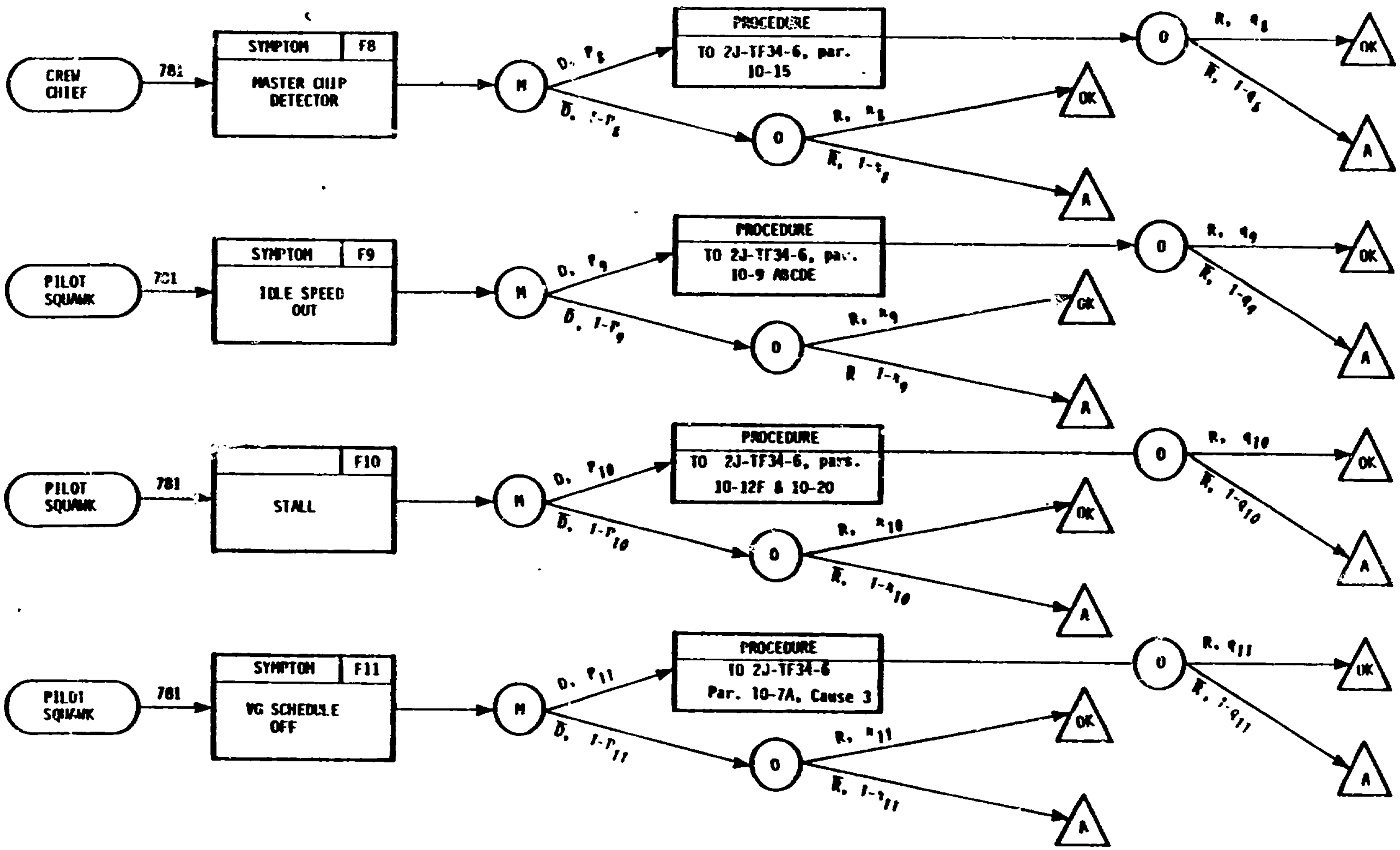

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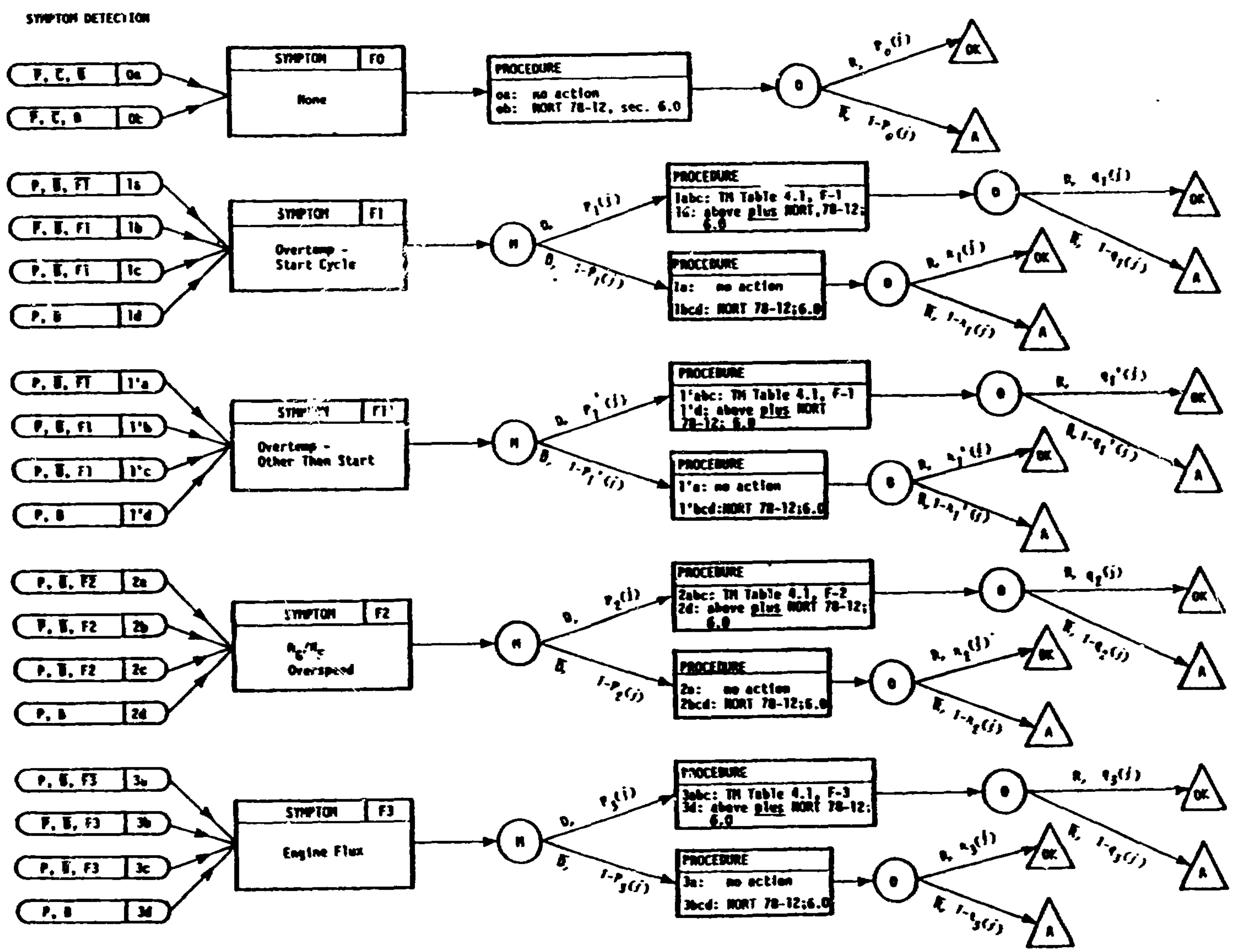
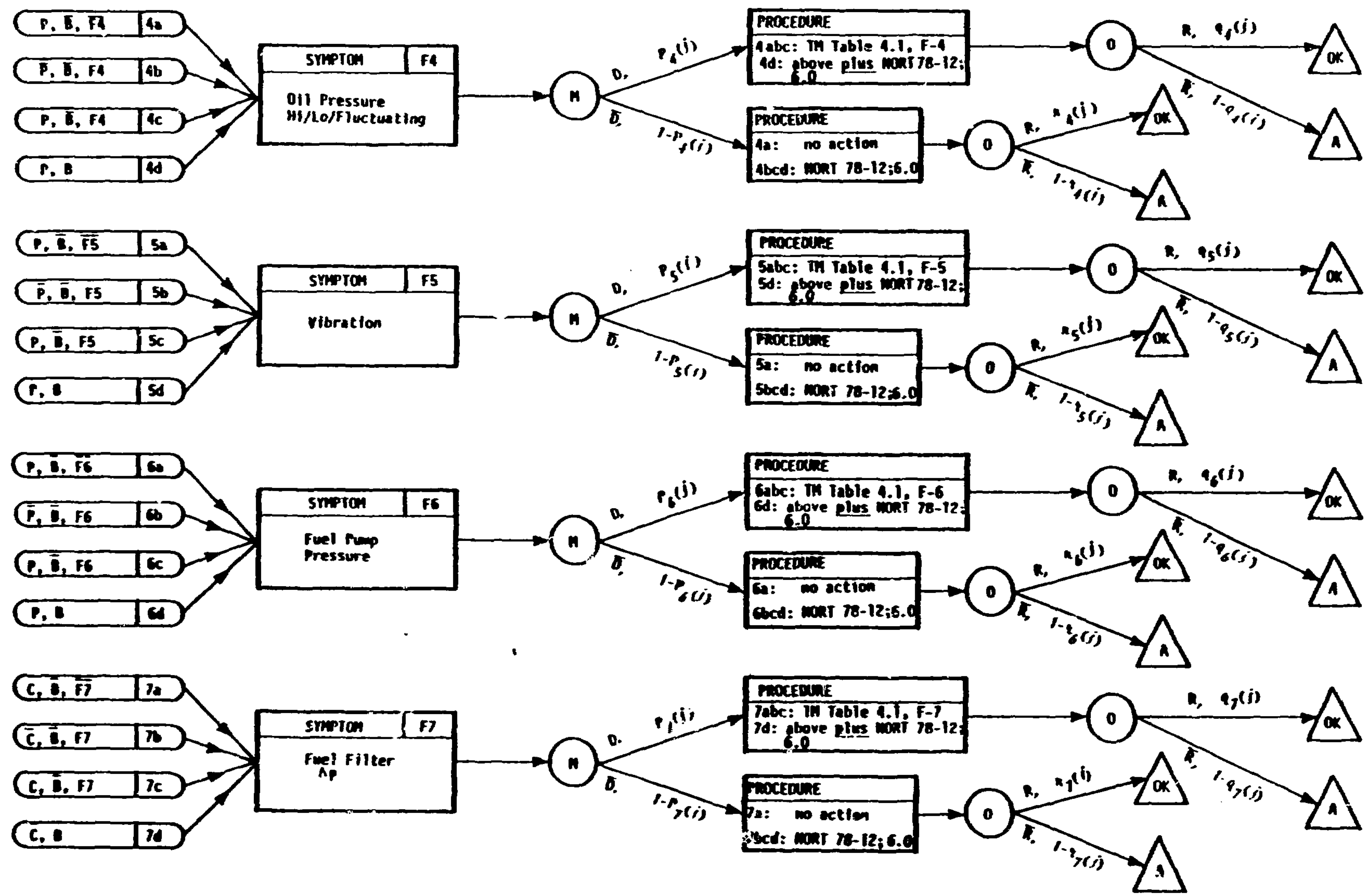


Figure 3.3 High Level TF34 Maintenance Diagram - With TEMS



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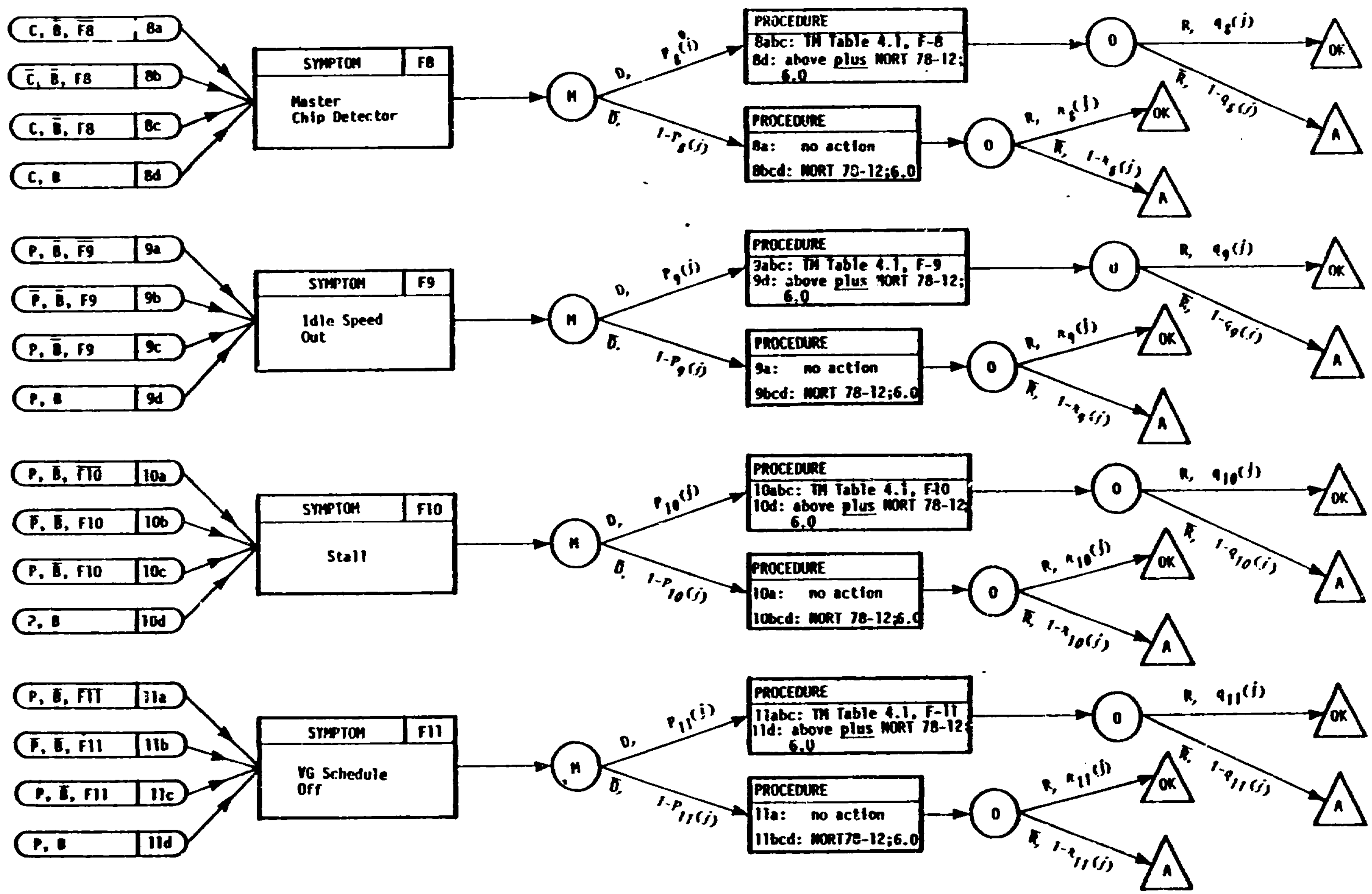


Figure 3.3 (Concluded)

Table 3.1

Key #1 To High Level Block Diagram Without TEMS

KEY

M: Maintenance test (ground run)

O: Operational test (fly next mission)

OK: Aircraft completes next mission

A: Aircraft aborts next mission

781: AF Form 781 (determines symptoms)

D: Duplicate symptom (in M)

$\overline{D}$: Symptom not duplicated (in M)

R: Engine runs in operational test (O)

$\overline{R}$: Engine problems in operational test (O)

MODEL PARAMETERS (*indicated in italics*)

p_0 = Probability next mission completed given no symptoms

q_i = Probability next mission completed given symptom i was detected, duplicated and troubleshooting done

P_i = Probability of duplicating symptom i in a ground test

r_i = Probability that the next mission is completed given symptom i was detected but not duplicated (and thus no troubleshooting done)

MODEL COSTS

(Can Be Incurred at M,O and Procedure Blocks)

C = Cost of block

M = Manhours required

TC = Engine test cycles used due to block

DT = Engine downtime due to block

TH = Engine test hours due to block

Table 3.2

Key #2 To High Level BLock Diagram With TEMS

KEY

M: a maintenance test or ground run

O: an operational test (i.e., check whether aircraft flies next mission)

R: successful completion of next mission by aircraft (engine runs)

$\overline{R}$: unsuccessful completion of next mission, by aircraft

OK: outcome of successful mission completion following O.

P: indicates a pilot squawk

$\overline{P}$: indicates no pilot squawk

Fi: denotes TEMS DDU display light Fi is on

$\overline{Fi}$: TEMS DDU display light Fi not on

ib: code for symptom i, detected by TEMS but not pilot

id: code for symptom i, detected by pilot with TEMS not operational

TM: denotes "USAF A-10 TEMS Training Manual"

NORT 78-12; 6.0: denotes A-10 TEMS Operating Instructions, Section 6.0

D: successful duplication of symptom in ground run (M)

$\overline{D}$: unable to duplicate symptom in ground run (M)

A: outcome of mission abort following O.

C: indicates detection of problem by crew chief

$\overline{C}$: indicates no detection of problem by crew chief

ia: code for symptom i, detected by pilot only (TEMS operational)

ic: code for symptom i, detected by pilot and TEMS

B: no go: TEMS built in test equipment (BITE)

$\overline{B}$: go: TEMS built in test equipment (BITE)

Table 3.2 (Continued)

KEY #3 TO HIGH LEVEL BLOCK DIAGRAM WITH TEMS

MODEL PARAMETERS (*appear in italics*)

$r_o(j)$:	probability of successful completion of next mission given no symptoms detected and event j
$p_i(j)$:	probability of successful duplication of symptom i in a ground run given detected by j
$q_i(j)$:	probability of successful completion of next mission given symptom i detected by j and duplicated in ground run
$r_i(j)$:	probability of successful completion of next mission given symptom i detected by j and not duplicated in ground run
i:	i is the index of symptoms, i.e., 1, 1', 2, 3, 4, ..., 11
j:	j indexes events by which the symptoms were detected, i.e., a, b, c, d

The rows in Figures 3.2 and 3.3 correspond to these symptoms. The symptom of overtemp is broken down further into "hot start" (symptom 1) and "other than start cycle" (symptom 1') due to the differing troubleshooting procedures for each.

For both models, the flow is from left to right. Symptoms are detected in one of four possible ways, labelled events. These are:

- event "a": pilot squawk only, TEMS okay
- event "b": only TEMS detects problem
- event "c": pilot and TEMS detect
- event "d": pilot squawk, TEMS not there or not operative

Without TEMS, only event "d' can occur while with TEMS, any of the events are possible. This accounts for the single versus multiple inputs into each row of the models in Figures 3.2 and 3.3.

Following symptom detection, a maintenance check (M) is done to try and duplicate the symptom. This check will depend on the symptom and can either be in the form of a ground run or some simpler test. Whether or not the symptom is duplicated is a chance node in the diagram.

Following the maintenance check, troubleshooting procedures are initiated. These depend on the symptom detection event and the result of the maintenance check. Procedures differ for the cases with and without TEMS. Procedure blocks on the diagrams indicate sources where they are documented. The troubleshooting procedure blocks include maintenance checks and repair or replacement actions. If a symptom is duplicated, or the TEMS built in test equipment (BITE) indicates a failure then troubleshooting is initiated on the engine. If the TEMS built in test equipment (BITE) indicates a failure (of TEMS) or if it does not but the symptom is not duplicated then troubleshooting is done on the TEMS. Otherwise, no action is taken and the engine

is given a functional check. The outcome of the functional check is either a working engine (OK) or an abort (A) in which case the engine or aircraft is sent back for further troubleshooting. It has been assumed that an aircraft which passes the functional check will also fly the next mission successfully.

Inputs to the high level block diagram models will include costs for actions and chance fork probabilities. Actions include maintenance and functional checks as well as troubleshooting and maintenance procedures. Chance forks occur at maintenance checks (outcomes = duplication or non-duplication of symptoms) and at functional or operational checks (outcomes = engine OK or not OK). The probabilities will change as a function of the symptom detection event (j). In the non-TEMS model there is only a single possible detection event (pilot squawk), thus chance fork probabilities appear as functions of symptom (i) only.

"Costs" are not limited to dollar values for outcomes or expenses incurred for actions. they include other possible objectives such as engine downtime, manhours, or engine test time.

3.2 DETAILED BLOCK DIAGRAMS

The purpose of the detailed block diagrams is to provide cost estimates for the procedure blocks in the high level decision models. The detailed diagrams are <u>not</u> decision analysis models, although they could be formulated as such. They model the details of various TF34 troubleshooting procedures. Figures 3.4 and 3.5 are the detailed diagrams for troubleshooting the symptom of an "overtemp, other than start cycle" respectively without and with TEMS. Table 3.3 provides a key to these diagrams while Tables 3.4 and 3.5 list and define the possible outcomes, without and with TEMS.

The model structure consists of checks (O), maintenance actions (□) and outcomes (△). Input required includes the

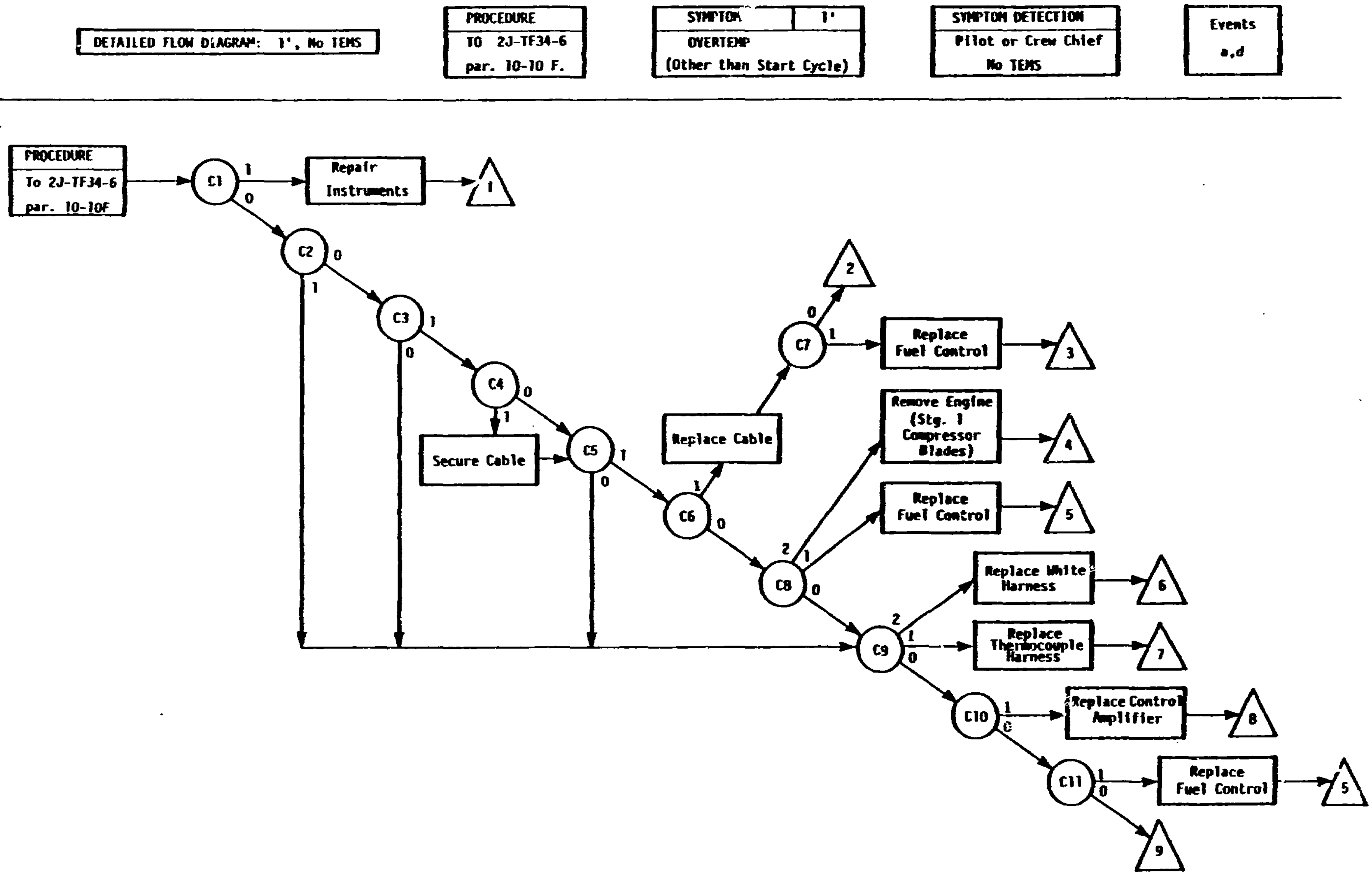


Figure 3.4 Detailed Flow Diagram, No TEMS

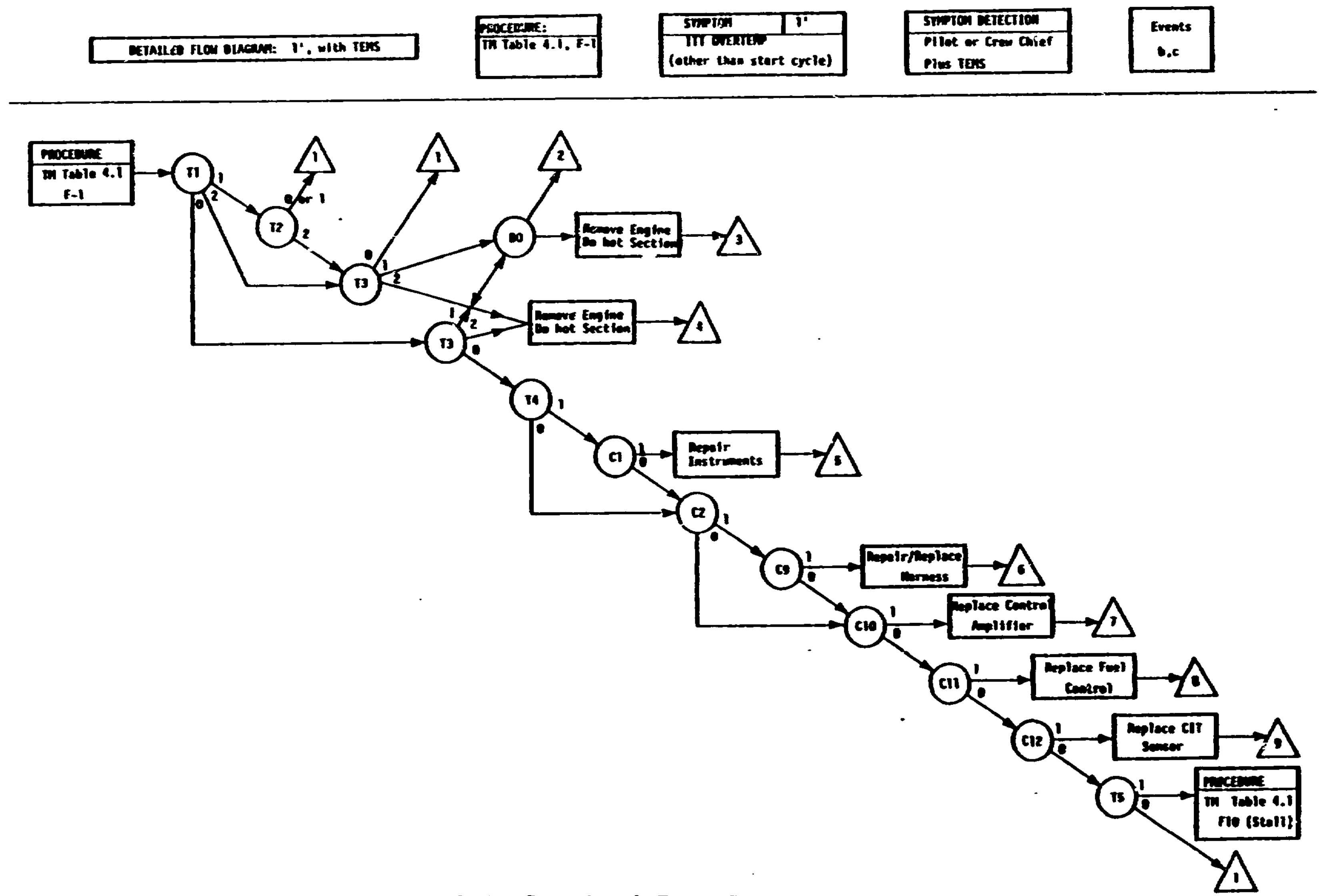


Figure 3.5 Detailed Flow Diagram, With TEMS

Table 3.3

Key #4 To Detailed Block Diagrams

TABLE OF CHECKS: SYMPTOM 1'

Checks Without TEMS

CODE	CHECK	OPTIONS
C1	Ng/ITT Indicator Systems	0,1
C2	Control Disable Check	0,1
C3	Ng Reaches 99-100% But ITT, Ng Remain Low	0,1
C4	Feedback Cable Secure?	0,1
C5	Feedback Cable Bound Up?	0,1
C6	Disconnect Feedback Cable: Does It Require More Than 4 lb. Force To Move?	0,1
C7	Feedback Cable: Has Problem Occurred Before on This Engine?	0,1
C8	Fuel Control Lever: Check Travel and Freedom Of Movement 2 = Hung Up, 1 = Binding, 0 = Okay	0,1,2
C9	Continuity Of Thermocouple and Junction Box 2 = ITT Overshoot if Disconnect J3, J4 1 = ITT Overshoot if Disconnect <u>One</u> of J3, J4 0 = No ITT Overshoots if Either J3, J4 disconnected	0,1,2
C10	Control Amplifier	0,1
C11	Torque Motor Winding Continuity	0,1
C12	Idle Speed 1 = Below 55%, 0 = Above 55%	0,1

Checks Requiring TEMS

T1	WF Override (G-7)	2 = On, PILOT Did Not Select 1 = On, PILOT Selected 0 = Not On
T2	F1 Display Light	2 = Level 2 1 = Level 1 0 = Not On

Table 3.3 (Continued)

TABLE OF CHECKS continued

CODE	CHECK	OPTIONS
T3	ITT Reading (B4)	2 = Greater Than 1000°C 1 = Between 927° and 1000°C 0 = Less Than 927°C
T4	Compare B1, B4, B5, C1 From Left and Right Engines	1 = All Agree Except B4 0 = Not Option 1
T5	F10 Light on DDU	1 = On 0 = Off
	Other Checks	
BO	Borescope Engine	1 = Problems Detected 0 = No Problems Detected

0: No Problem Detected

1: Problem Detected

Table 3.4

Key #5 To Detailed Block Diagram Without TEMS

TABLE OF OUTCOMES FOR	PROCEDURE
	TO 2J-TF34-6 Par. 10-10F.

1. Repair Instruments
2. Replace Feedback Cable
3. Replace Feedback Cable and Fuel Control
4. Remove Engine
5. Replace Fuel Control
6. Replace White Harness
7. Replace Thermocouple Harness
8. Replace Control Amp
9. No Repair / Replacement

Table 3.5

Key #6 To Detailed Block Diagram, With TEMS

TABLE OF OUTCOMES FOR:	PROCEDURE
	TM Table 4.1, F-1

1	No Maintenance Action
2	Borescope Engine
3	Borescope and Remove Engine
4	Remove Engine
5	Repair Instruments
6	Repair/Replace Harness
7	Replace Control Amp
8	Replace Fuel Control
9	Replace CIT Sensor

PROCEDURE	
TM Table 4.1 F10 (Stall)	Check for Stall

"costs" of the various checks and actions as well as the expected frequency of each outcome. Given these inputs and the maintenance procedure, costs and frequency for each outcome are computed. By weighting outcome costs by their frequencies, an expected procedure "cost" can be computed and used as input in the appropriate high-level block diagram model.

IV. MODEL EVALUATION PLAN

This section describes an evaluation plan for the maintenance models presented in Section III. Included in this plan are model evaluation criteria and data requirements, prospective data sources and collection methods for model inputs, and solution techniques.

Decision analysis models as discussed in Section 2.1 require as input the chance fork probabilities, costs for decisions, values for outcomes and utility functions demonstrating the risk preferences of the decision-maker. Table 4.1 lists data requirements other than utility functions. These are classified as model parameters (chance fork probabilities in the high level models and symptom detection event frequencies) and model costs. "Costs" are defined in terms of the multiple model evaluation criteria. These include $-cost, manhours required, engine downtime, engine test hours and engine test cycles required to complete the various checks, maintenance actions and tests which appear in the models of Section III. Also required to produce "costs" are the probabilities of occurrence for each outcome of the detailed block diagram models.

The final data requirement is a utility function representing the decision-maker's preference for various decision model outcomes as a function of those outcomes. The simplest utility (linear function) is exhibited by a person who acts solely on the basis of expected return. A "risk averse" person will be more apt to choose a policy which will protect himself against bad outcomes while trading off some of his expected return. A utility function quantifies this behavior in an individual. In absence of other information, the "expected value" assumption is often made.

Data sources for the aforementioned model input data requirments are summrized in Figure 4.1. In the figure, data

Table 4.1

Data Requirements

I. MODEL PARAMETERS

A. $P_i(j)$, $i = 1, 1', 2, \ldots, 11$ and $j = a, b, c, d$
= probability pilot or crew chief detects symptom i and ground run duplicates it
(a measure of pilot reliability)

B. $q_i(j)$, $i = 1, 1', 2, \ldots, 11$ and $j = a, b, c, d$
= probability functional check is successful given pilot detects and ground run duplicates symptom i
(a measure of maintenance effectiveness or reliability)

C. $r_i(j)$, $i = 1, 1', 2, \ldots, 11$ and $j = a, b, c, d$
= probability that functional check is successful given the pilot detects but the ground run is unable to duplicate symptom i
(1-r is a measure of ground run reliability)

D. $P_0(j)$, $j = a_0, b_0$
= probability next mission is successful given no symptoms detected

E. Pa, Pb, Pc, Pd, the relative frequencies of events
Pa_0, Pb_0
($Pa + Pb + Pc + Pd = 1$ and $Pa_0 + Pb_0 = 1$)

Where

event	a: $P, \overline{B}, F_i$	c: $P, \overline{B}, F_i$	a_0: $\overline{P}, \overline{B}, \overline{F}_i$ all i
	b: $\overline{P}, B, F_i$	d: P, B	b_0: $\overline{P}, B$

II. MODEL COSTS

A. Cost ($)

1. For each check (0) in detailed flow diagrams
2. For each action (□) in detailed flow diagrams
3. For each test (M or 0) in high-level diagrams

B. Manhours to complete

1. checks
2. actions
3. tests

Table 4.1 (Continued)

DATA REQUIREMENTS continued

C. Engine downtime due to:

   1. checks
   2. actions
   3. tests

D. Hours of engine test required

   1. checks
   2. actions
   3. tests

E. Cycles of engine test required

   1. checks
   2. actions
   3. tests

F. Outcome probabilities

   1. For each check (O) in detailed flow diagrams

III. VALUES OF "OUTCOMES" FOR HIGH LEVEL FLOW DIAGRAMS

A. Cost of next mission abort or engine functional check failure.

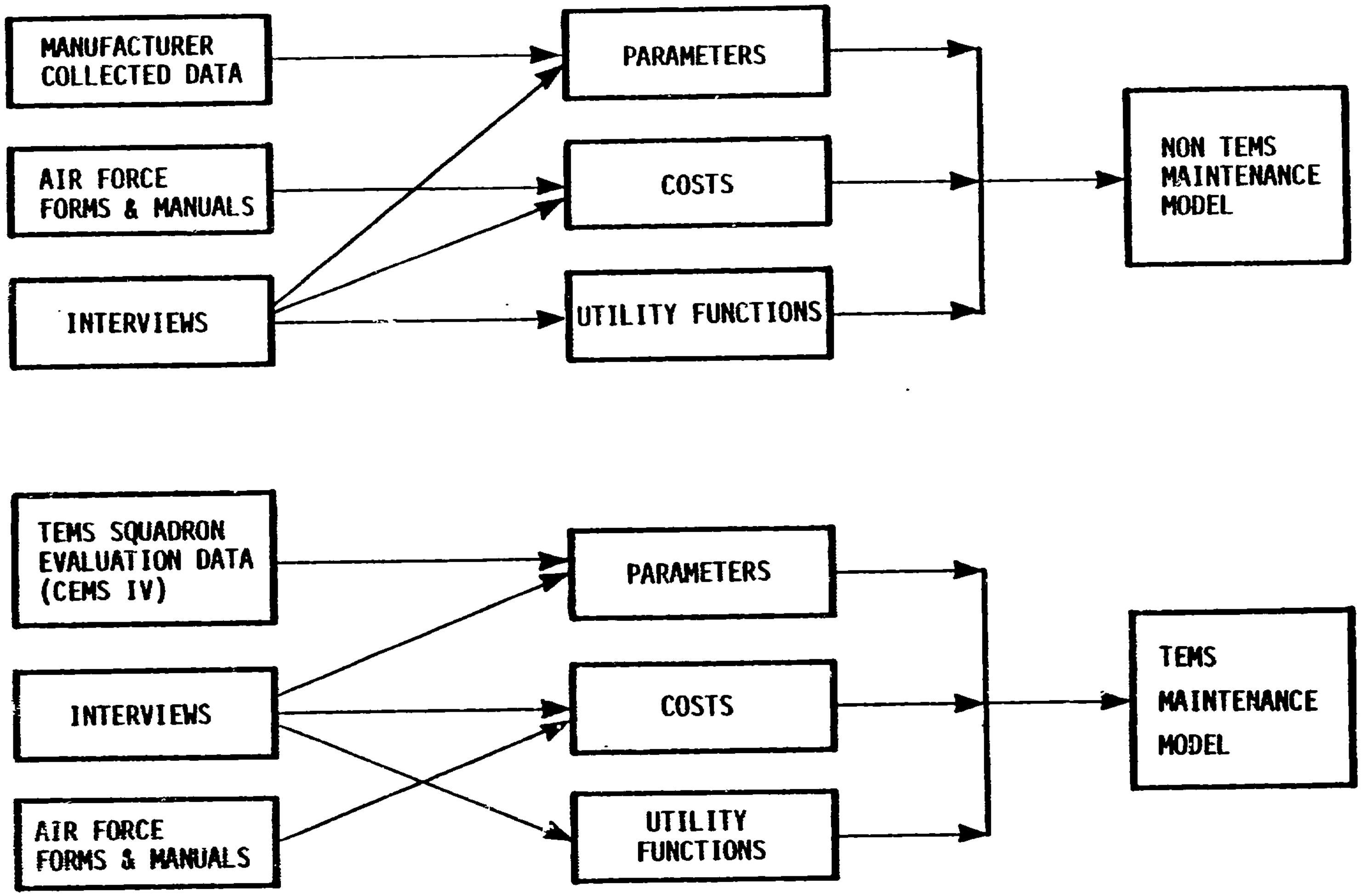


Figure 4.1 Modeling Procedure: Information and Data Flow

source categories are on the left, data requirements in the middle and models in the right column. Without TEMS, model parameters can be determined through manufacturer collected AFTO 781E and 349 data. For example, General Electric has collected 412,000 TF34 engine flying hours from 1976-1980 of data on inflight power losses, shutdowns, aborts, LRU maintenance and shop visits. Event occurrences are logged along with detailed cause (e.g. T2 inlet sensor removal).

With TEMS, the data has not yet been collected but a unique opportunity exists from Oct. 1982 through Oct. 1983 to use the CEMS IV prototype system for collection of such data from the TEMS squadron evaluation.

Model costs will be determined through compilation of information in various Air Force documents. These are listed in Table 4.2. This table provides a more detailed listing of other data sources. Utility functions cannot be obtained other than through interviews with the decision maker.

Given the models of Section III and a set of input data, the detailed block diagrams must first be evaluated to provide costs for the "procedure" blocks in the high level diagram decision analysis models. The high level models can then be evaluated using standard techniques discussed in Section 2.1 under model evaluation.

Table 4.2

Table of Data Sources

DATA	PRIMARY SOURCE	SECONDARY SOURCE
$P_i(j)$	AFTO 781 E Form AFTO 349 Form (AFM 66-1 - MDCS)	CEMS IV Database
$q_i(j)$	AFTO 781 E Form AFTO 349 Form (AFM 66-1 - MDCS)	CEMS IV Database
$r_i(j)$	AFTO 781 E Form AFTO 349 Form (AFM 66-1 - MDCS)	CEMS IV Database
Freqs. of Events	CEMS IV Database	TEMS Squadron Test Log
Costs $	AF Cost Standards (Quantitative Judgment (Interviews)	
Manhours	AFM 66-1 (MDCS)	
Engine Downtime	AFTO 1534 Form (D024 Status Reporting)	AFTO 349 (AFM 66-1 - MDCS)
Engine Test Hrs./Cycles	TEMS Test Log	
Fault Distribution	Manufacturer Support Data System	

V. AN EXAMPLE

To illustrate the decision analysis model evaluation procedure, a simple example is now solved. The portion of the high level block diagram without TEMS for the symptom of overtemp, other than during start cycle has been expanded to include alternative decisions to Air Force policy as described in TO-2JTF34-6. An option has been added for doing a ground run or not in the maintenance check. Following this check, an option to troubleshoot (includes maintenance) or not has been added except in the case where a ground run is done and the symptom is duplicated. In this case, it has been assumed that troubleshooting will always be done. Note that the level of troubleshooting is greater following a ground run. Troubleshooting without a ground run would only be a simple procedure capable of detecting and fixing only minor problems.

The input data were selected to exhibit the following "reasonable" properties: For this symptom, duplication through a ground run is unlikely. Also, the probability that an engine functional check turns out okay is proportional to the extent of troubleshooting. Thus the minimal troubleshooting done without a ground run, while not costing much, does not yield much chance of working engine.

The "costs" are "relative" factors intended to encompass all quantitative and qualitative objectives into a single number on a scale of 1-10, ten being the most expensive or the "worst". Again, the cost of the more extensive troubleshoot following a ground run is much higher.

The utility function has been assumed to be linear so the decision-maker is choosing an option based on expected value outcome.

Figure 2.2 exhibits the decision tree for this example. Notation is the same as for the models of Section III with

additions listed on the figure. Probabilities of chance fork outcomes are in parentheses while costs and values are circled.

Table 5.1 shows the solution to the example. There are four possible policies:

(1) Gt: do a ground run and if symptom not duplicated then troubleshoot

(2) $G\bar{t}$: do a ground run and if symptom not duplicated, do not troubleshoot (TO 2JTF34-6 policy)

(3) $\bar{G}t$: do not do a ground run and do minor troubleshoot

(4) $\bar{G}\bar{t}$: do not do a ground run and do not troubleshoot (ignore the problem)

In this case the optimal policy turns out to be Gt with a mean cost of 6.35.

Table 5.1

POSSIBLE OUTCOMES

POLICY	#	COST	PROB.	#	COST	PROB.	#	COST	PROB.	#	COST	PROB.	MEAN COST
Gt	1	6	.285	2	13	.015	3	6	.665	4	13	.035	6.35
$G\bar{t}$	1	6	.285	2	13	.015	5	2	.21	6	9	.49	6.75
$G\bar{t}$	7	1	.15	8	8	.85							6.95
$\bar{G}\bar{t}$	9	0	.05	10	7	.95							6.65

OPTIMAL SOLUTION: Gt

MEAN COST: 6.35

VI. CONCLUSIONS AND RECOMMENDED FUTURE WORK

In this section, SCT's conclusions resulting from this study as well as an outline for recommended future work will be presented.

The main points to be learned from this study are:

- The technique of decision analysis is a very flexible and useful tool for determining optimal maintenance procedures, optimal decision making techniques (human factors) and optimal utilization of TEMS information.

- To pursue a maintenance decision analysis and improvement program optimally, accounting for human as well as logistics factors, decision analysis is an ideal tool. It has already been applied successfully in numerous areas in medicine and management. Any group attempting to attempt such an effort should have expertise in decision analysis methods, human factors and the logistics of TF34 maintenance. This supports the conclusion made in Ref. 12.

- Data is available for model evaluation. A unique opportunity exists to use CEMS IV to collect data for analysis of decision making methods and for input into maintenance decision analysis models. The period of this opportunity will extend from October 1982 through October 1983.

- A need exists for a study as outlined in the previous conclusions. The remainder of this section outlines some of the issues involved, work breakdown structure and a schedule of events for such a study.

Henceforth, future work in this area will be referred to under the header: "Maintenance Decision Analysis and Improvement Program" (MDAIP). The objectives of the program will be to:

(1) Evaluate TEMS through decision model analysis accounting for both human and logistics factors. This will occur in Phase I of the proposed work breakdown structure appearing in Table 6.1.

Table 6.1

Maintenance Decision Analysis and Improvement Program

WORK BREAKDOWN STRUCTURE

PHASE I: DECISION MODEL ANALYSIS

- **TASK 1: - HARDWARE SELECTION**
- **TASK 2: - MAINTENANCE PROCESS MODEL APPLICATION**
  - KEY DECISIONS
- **TASK 3: - DATA COLLECTION**
- **TASK 4: - MODEL EVALUATION**
- **TASK 5: - DOCUMENTATION**

WORK BREAKDOWN STRUCTURE

PHASE II: OPTIMAL POLICY DETERMINATION

- **TASK 1: - INVESTIGATE ALTERNATIVE DECISIONS**
- **TASK 2: - DEVELOP MEASUREMENT PLAN**
- **TASK 3: - UTILIZE MEASUREMENT PLAN**
- **TASK 4: - IDENTIFY CORRECTIVE MEASURES**
- **TASK 5: - CONDUCT FIELD TEST**
- **TASK 6: - PREPARE DOCUMENTATION**

(2) Determine optimal policies to help Air Force set guidelines for maintenance with TEMS. These policies should include maintenance procedures, decision making techniques and incorporate optimal usage of TEMS information. This effort will occur as Phase II of the proposed program.

Phase I will involve running through the decision analysis cycle the first time using only a moderate data collection effort, while testing the models. Task 1 involves the selection of hardware on which to perform the analysis. The models of Section III amplified to incorporate certain key decisions will be installed on the selected hardware as part of Task 2. All software developed or used in Phase I should be in suitable format for easy model revision in Phase II. In Tasks 3 and 4, input data will then be collected from sources requiring only a moderate collection effort and the models evaluated (with and without TEMS). Evaluation will encompass current maintenance strategy, decision making methods and automated equipment installation. Documentation of these results occurs as Task 5.

Phase II, the major thrust of this future effort will involve the investigation of alternative maintenance decisions and decision making methods possible under TEMS. In task 1, alternatives will be investigated in. Possible alternatives will be examined for both the high level models (initial ground runs? levels of troubleshooting?) and the detailed models (changing details of maintenance process). Items influencing the choice of maintenance decision alternatives include BITE and automated monitoring unit (AMU) effectiveness as well as decision-maker reliability, validity and efficiency.

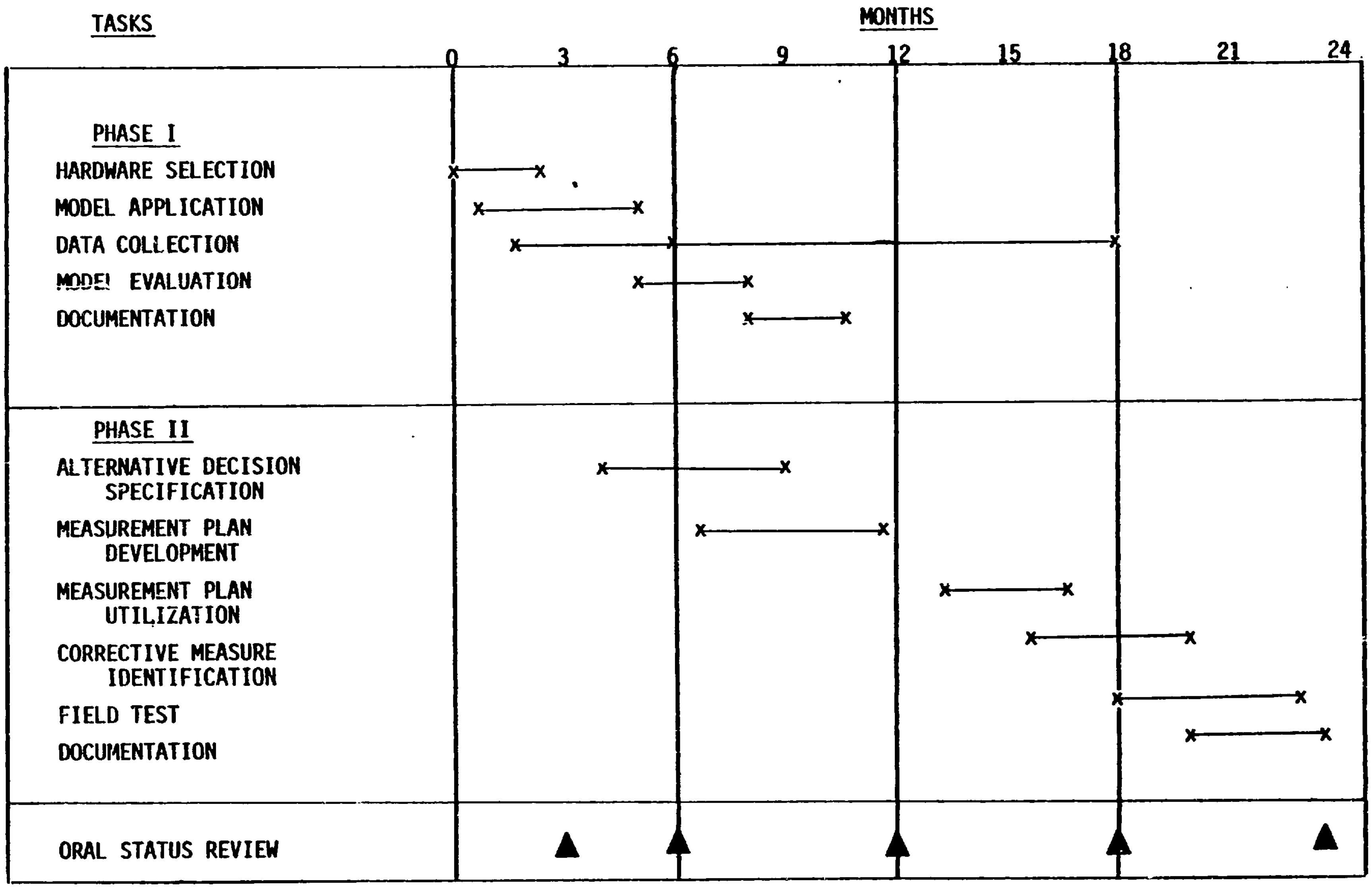
Following the investigation of alternative decisions, a measurement plan (Task 2) will be developed for collection of data for input to a revision of the Phase I model. This plan will be one for which the expected benefits in terms of model results exceed the expected cost of data acquisition.

In Tasks 3 and 4, the measurement plan will be carried out and model evaluation performed. Based on these results,

corrective measures for optimizing Air Force maintenance under TEMS will be recommended. These will then be implemented in a field test to validate model results. Results will be documented (Tasks 5 and 6). Table 6.2 presents a proposed two-year schedule for MDAIP performance.

Table 6.2

Maintenance Decision Analysis and Improvement Program Schedule



VII. ADDITIONAL DETAILED DIAGRAMS FOR TF34 MAINTENANCE PROCESS

The following set of block diagrams provide additional details on the TF34 maintenance process. These diagrams have been tailored to provide a clear understanding of the range of decisions and maintenance actions over all possible symptoms as well as to point out where the human or judgemental factors enter into the models.

Two types of diagrams are included: full detailed diagrams for symptom 1 (overtemp, nonstart cycle) and subsets of detailed block diagrams consisting of paths leading to an engine removal or replacement decision.

Figures 7.1 and 7.2, full detailed block diagrams, are nearly identical to Figures 3.4 and 3.5 except for minor modifications introduced to emphasize the decision points in the maintenance flow, even when restricted to policies specified in Refs. 9 and 10. Each check labeled with a "C" is performed by a maintenance specialist and as such the outcome is affected by his judgement. Decisions resulting from checks labeled with "T" are based on TEMS display lights and can be considered to be non-judgemental in nature. The key to Figures 7.1 and 7.2 is found in Tables 3.3 through 3.5. Diagonal shaped boxes have replaced circles to represent decison points in the maintenance process.

Figures 7.3 through 7.10 are subsets of the full detailed block diagrams. Only decisions which could lead to an engine removal are pictured. Notation is the same as for other detailed diagrams: ellipses represent inputs while diamonds represent decisions based on the results of various checks or inspections specified by the code inside the box. These codes are explained in Table 7.1. Rectangular boxes represent simple actions while "R" represents the outcome of engine removal or replacement.

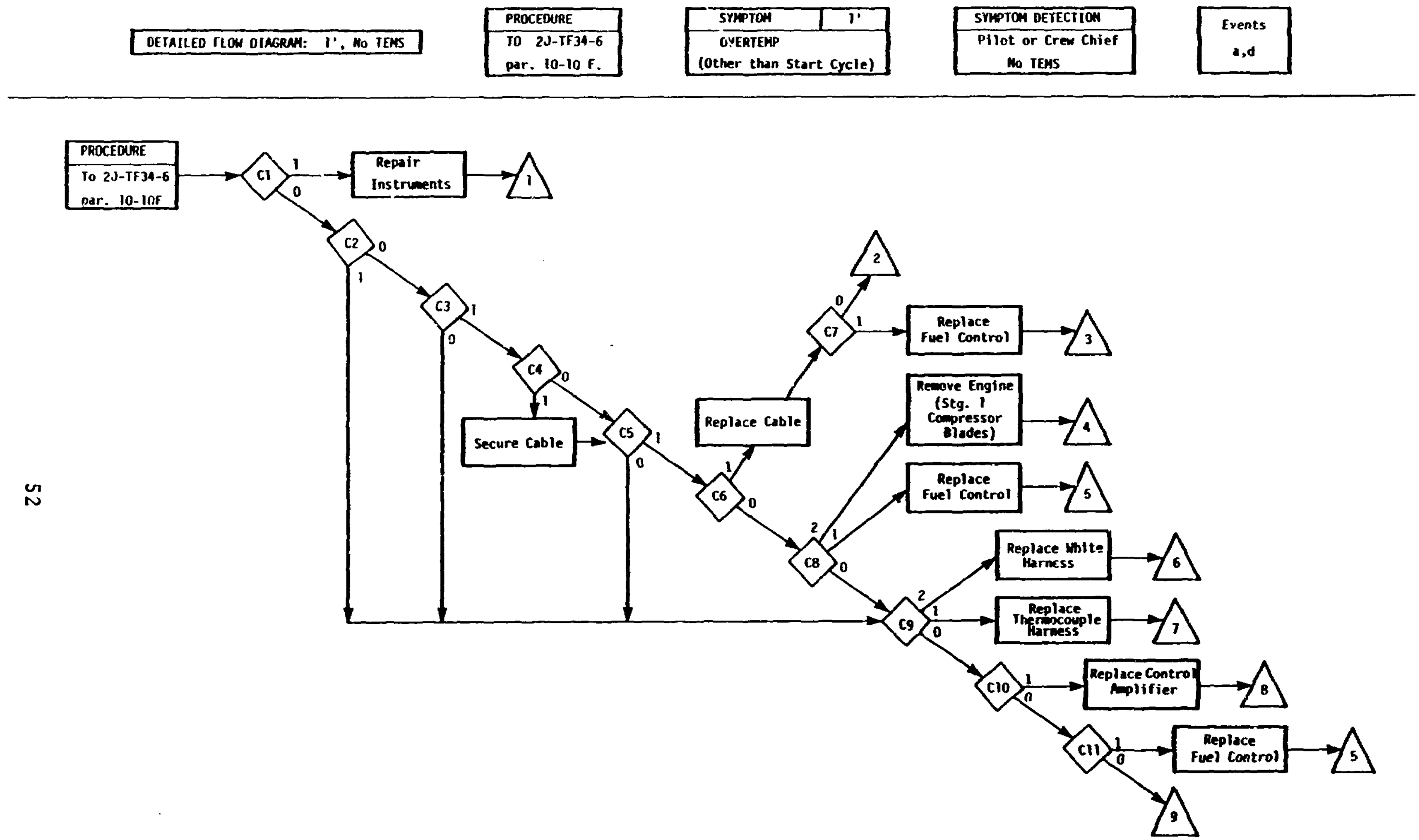


Figure 7.1 Revised Detailed Flow Diagram, No TEMS

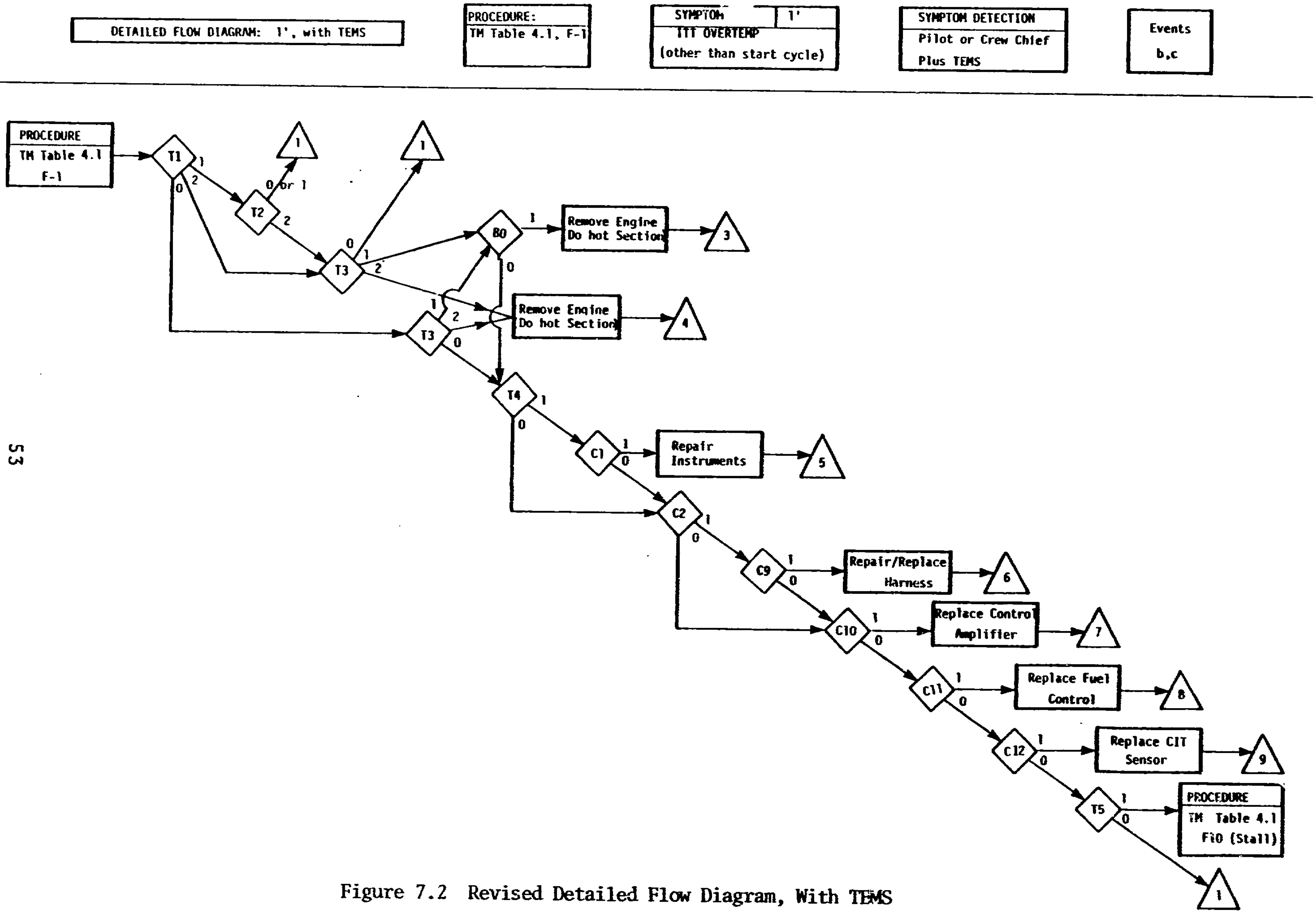


Figure 7.2 Revised Detailed Flow Diagram, With TEMS

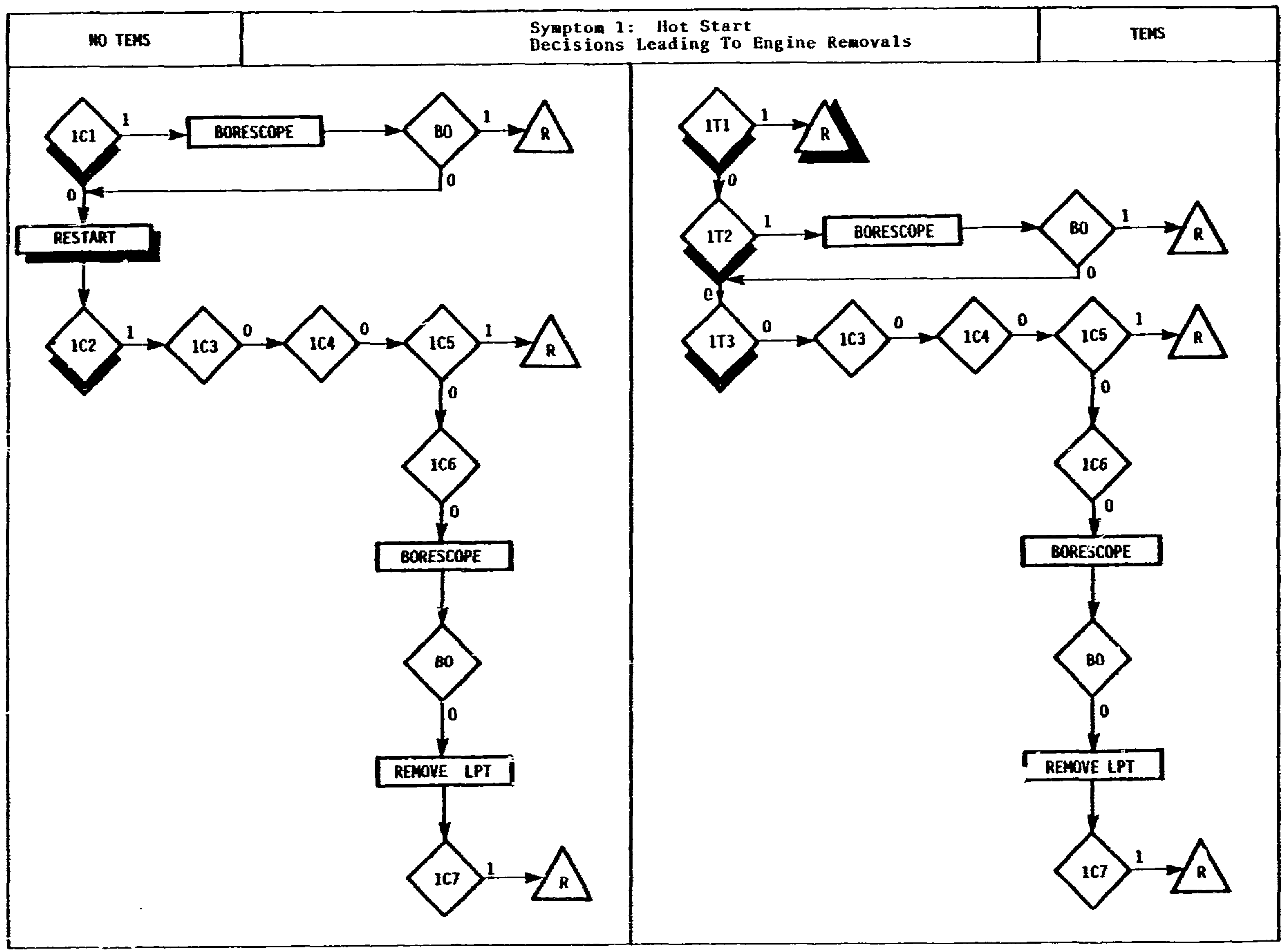


Figure 7.3 Symptom 1

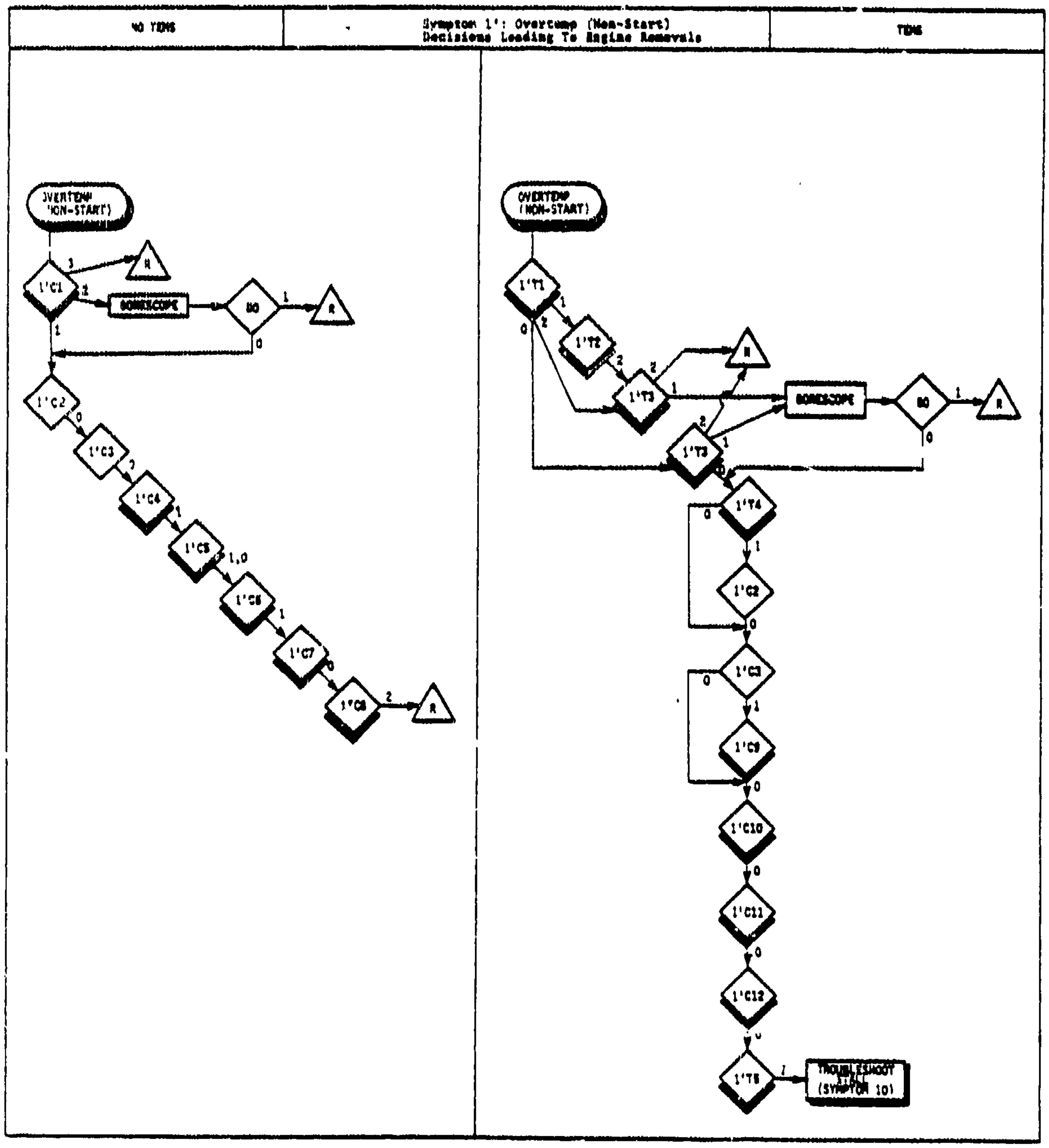


Figure 7.4 Symptom 1'

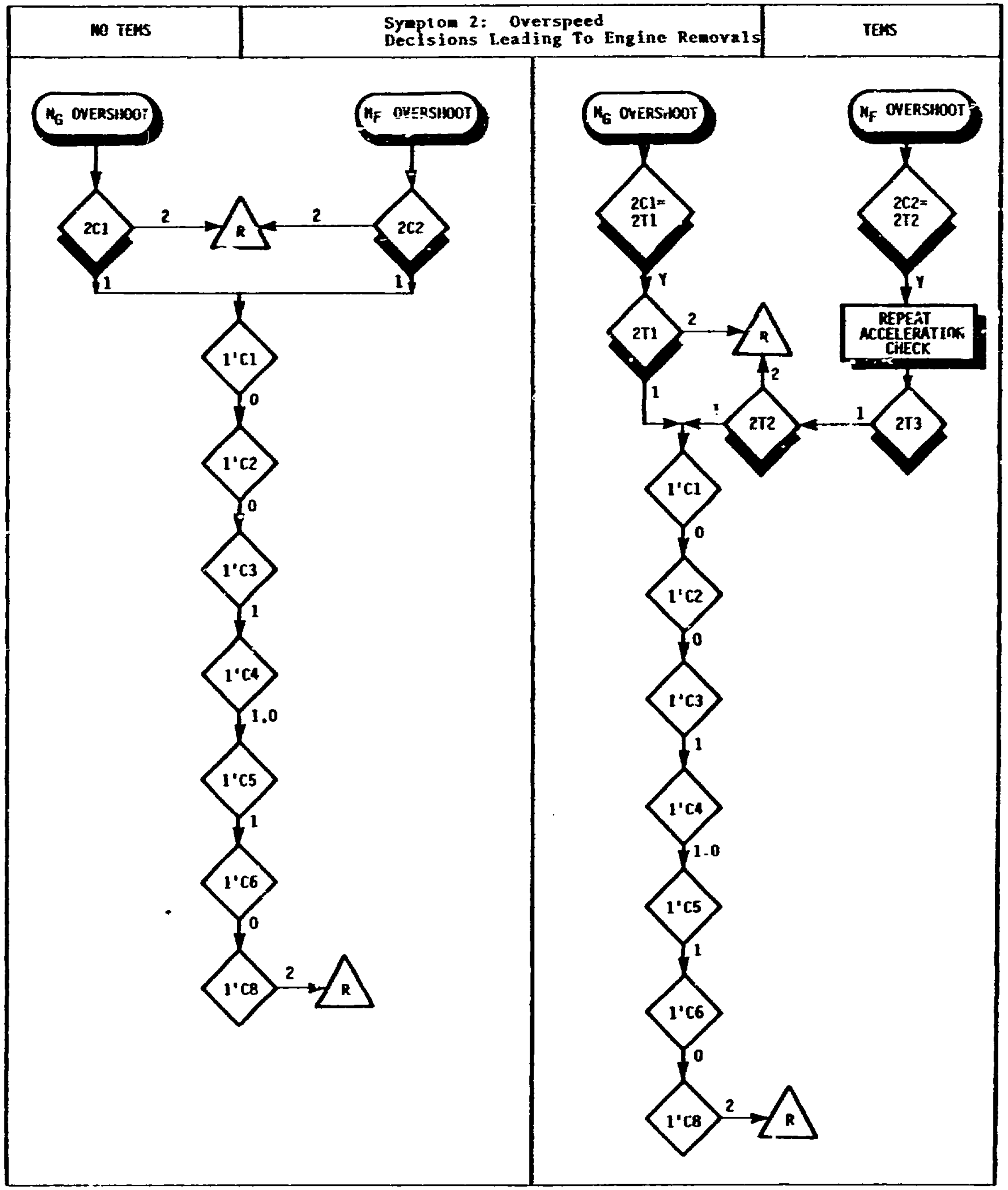


Figure 7.5 Symptom 2

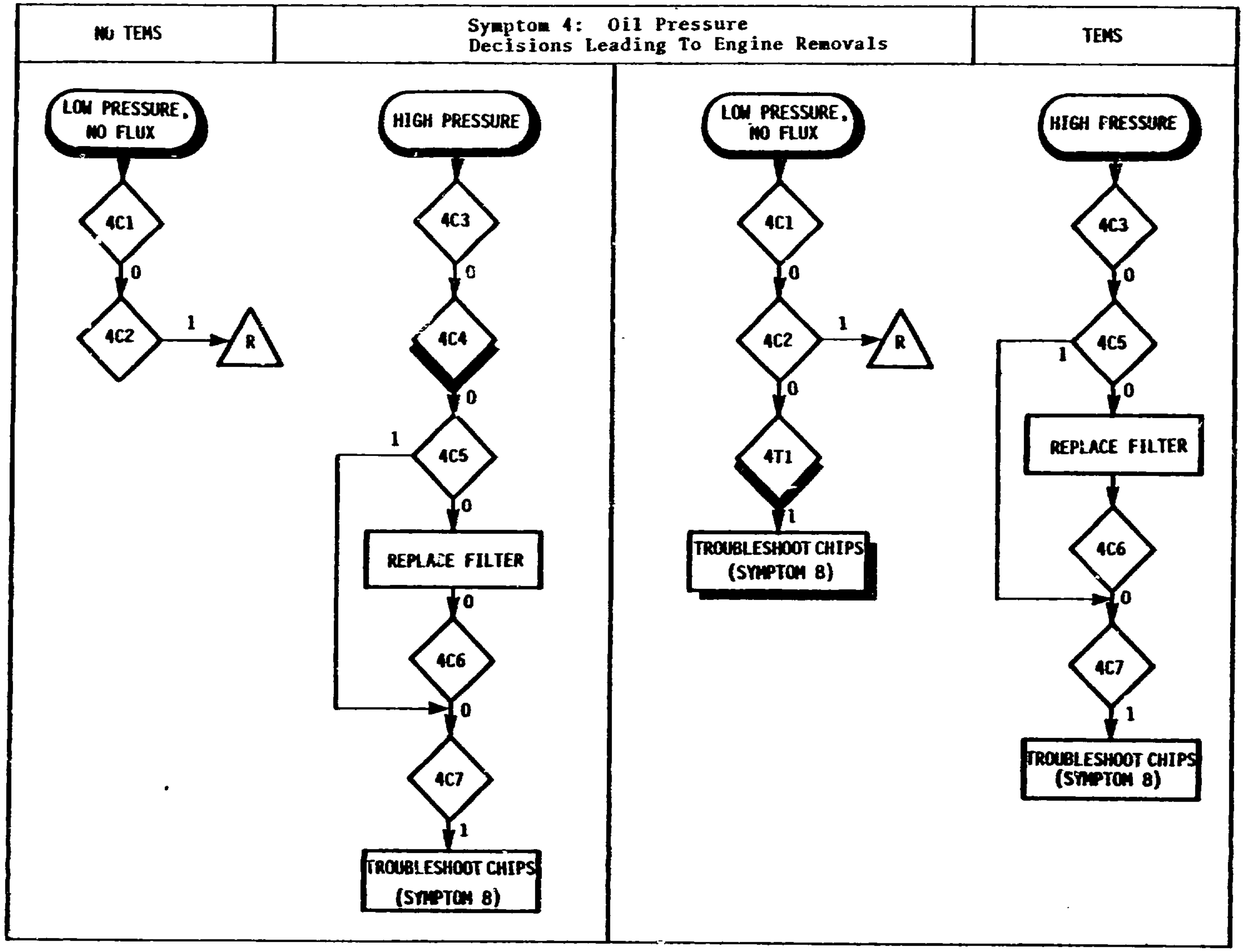


Figure 7.6 Symptom 4

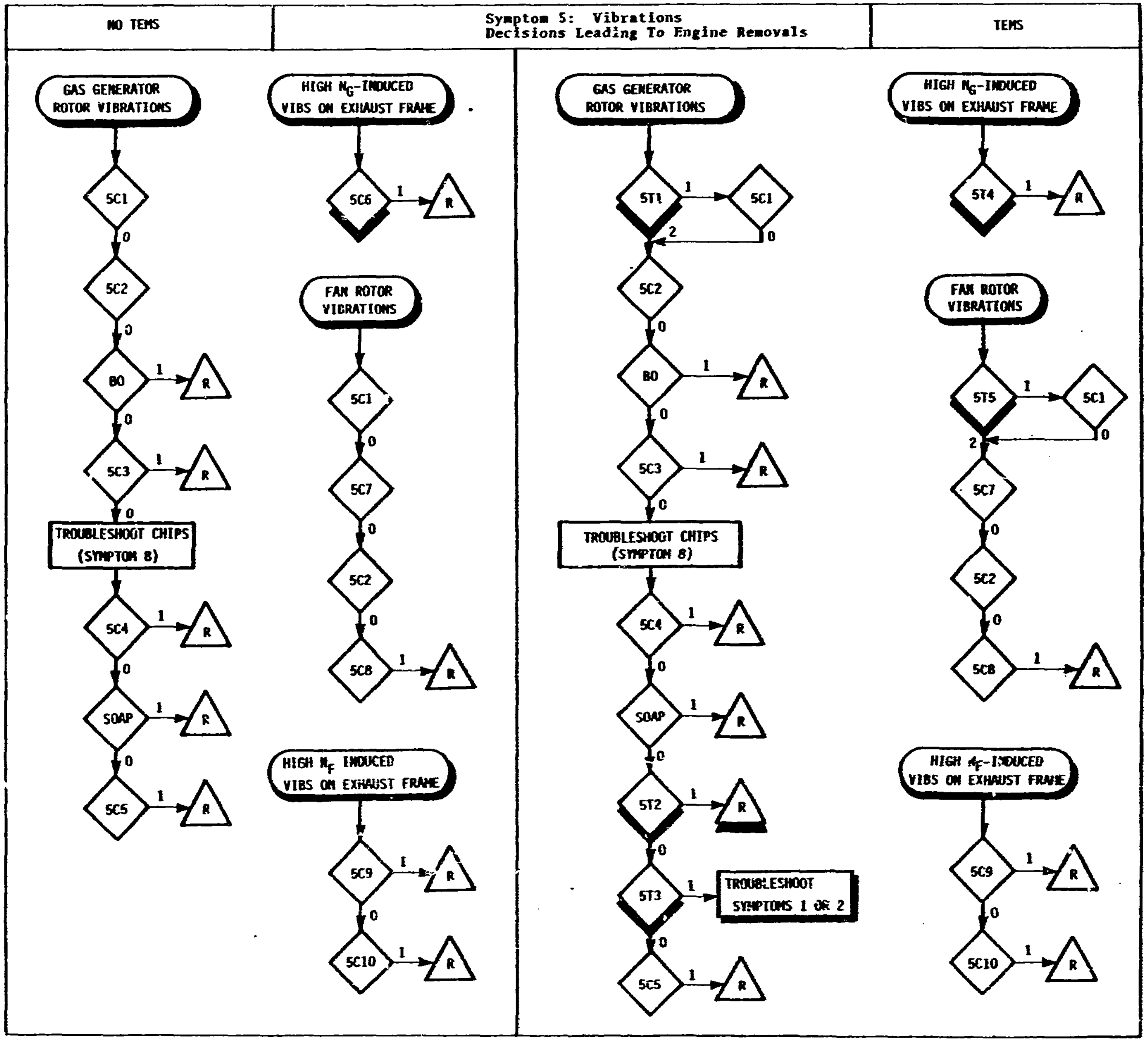


Figure 7.7 Symptom 5

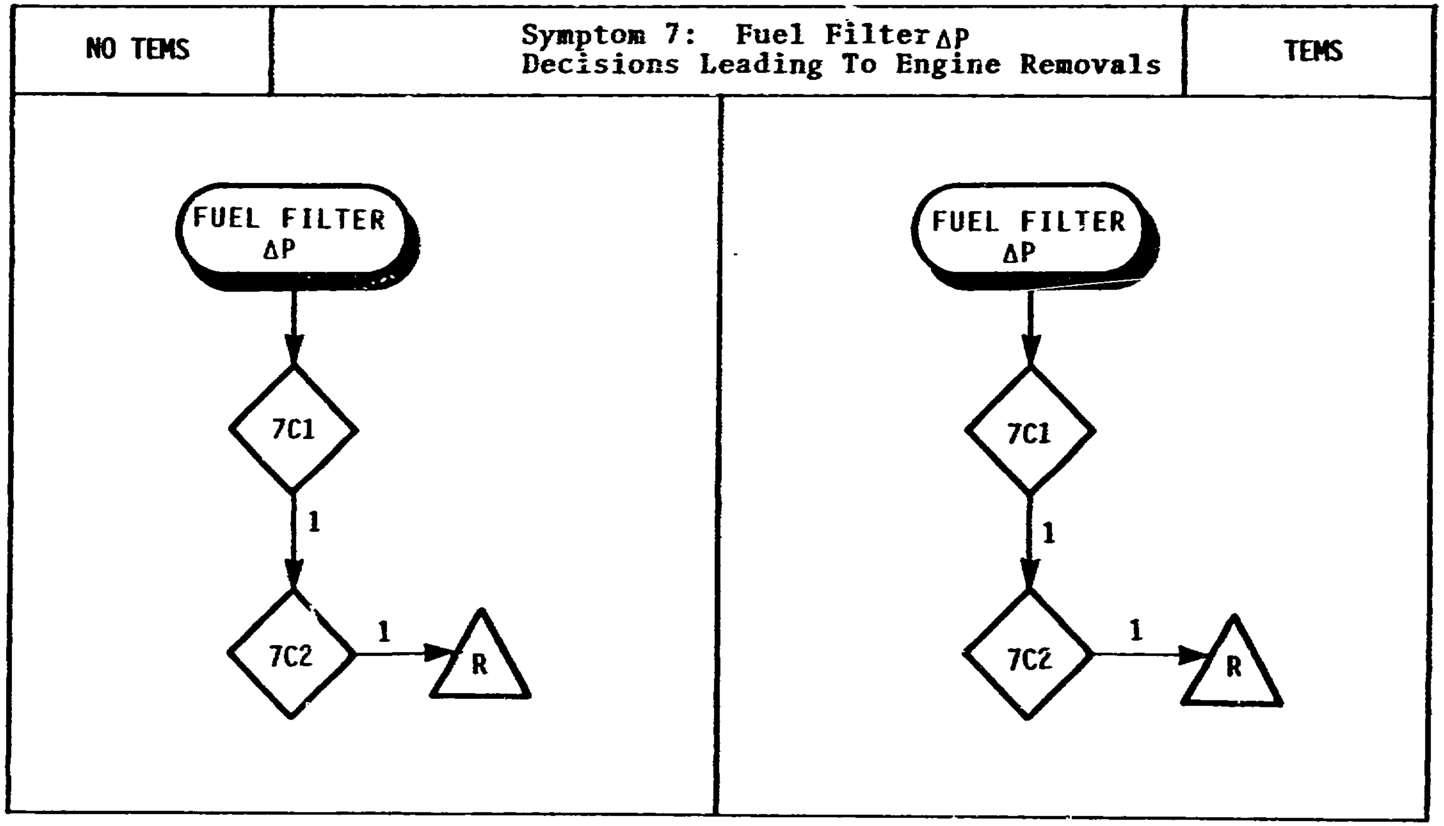


Figure 7.8 Symptom 7

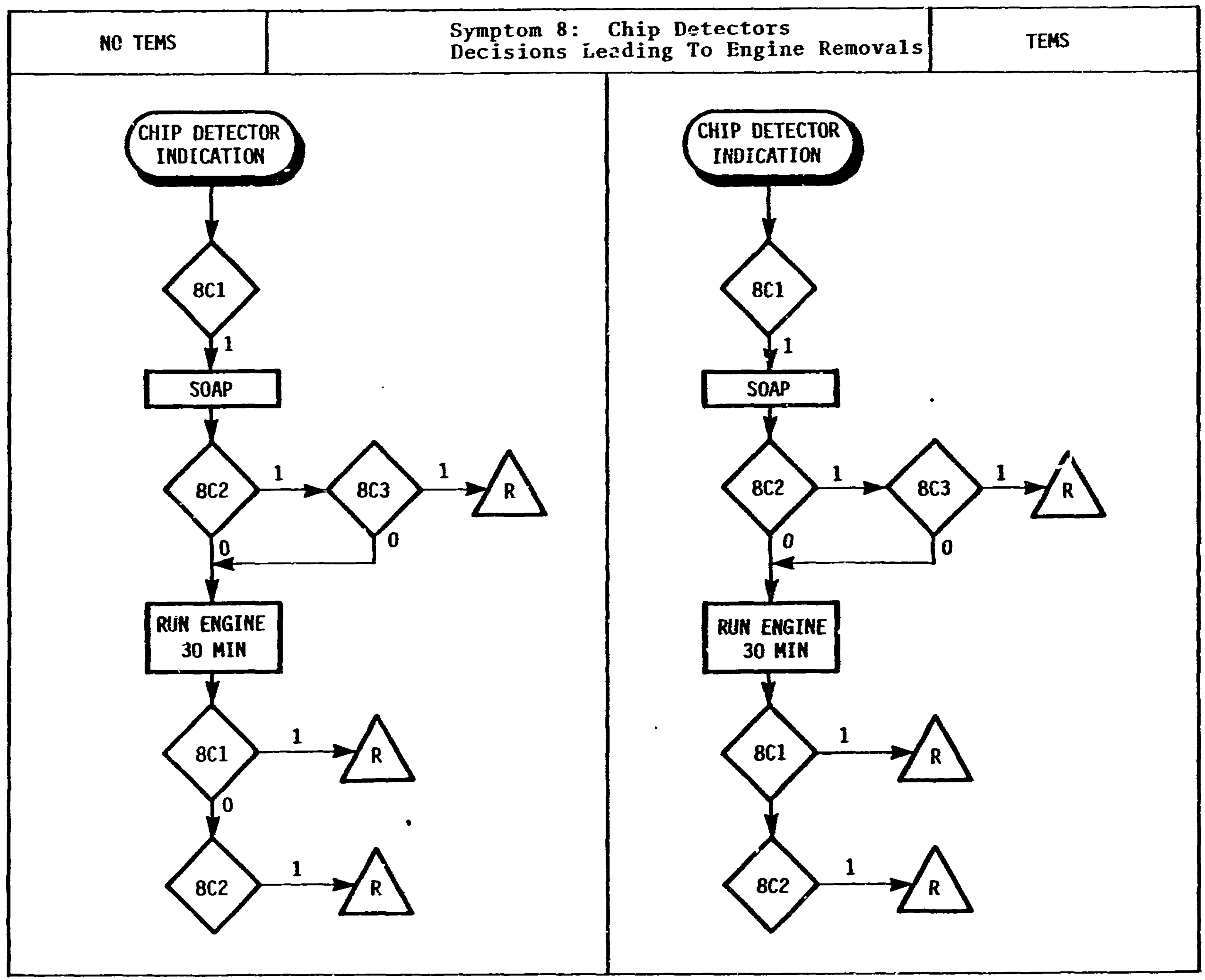


Figure 7.9 Symptom 8

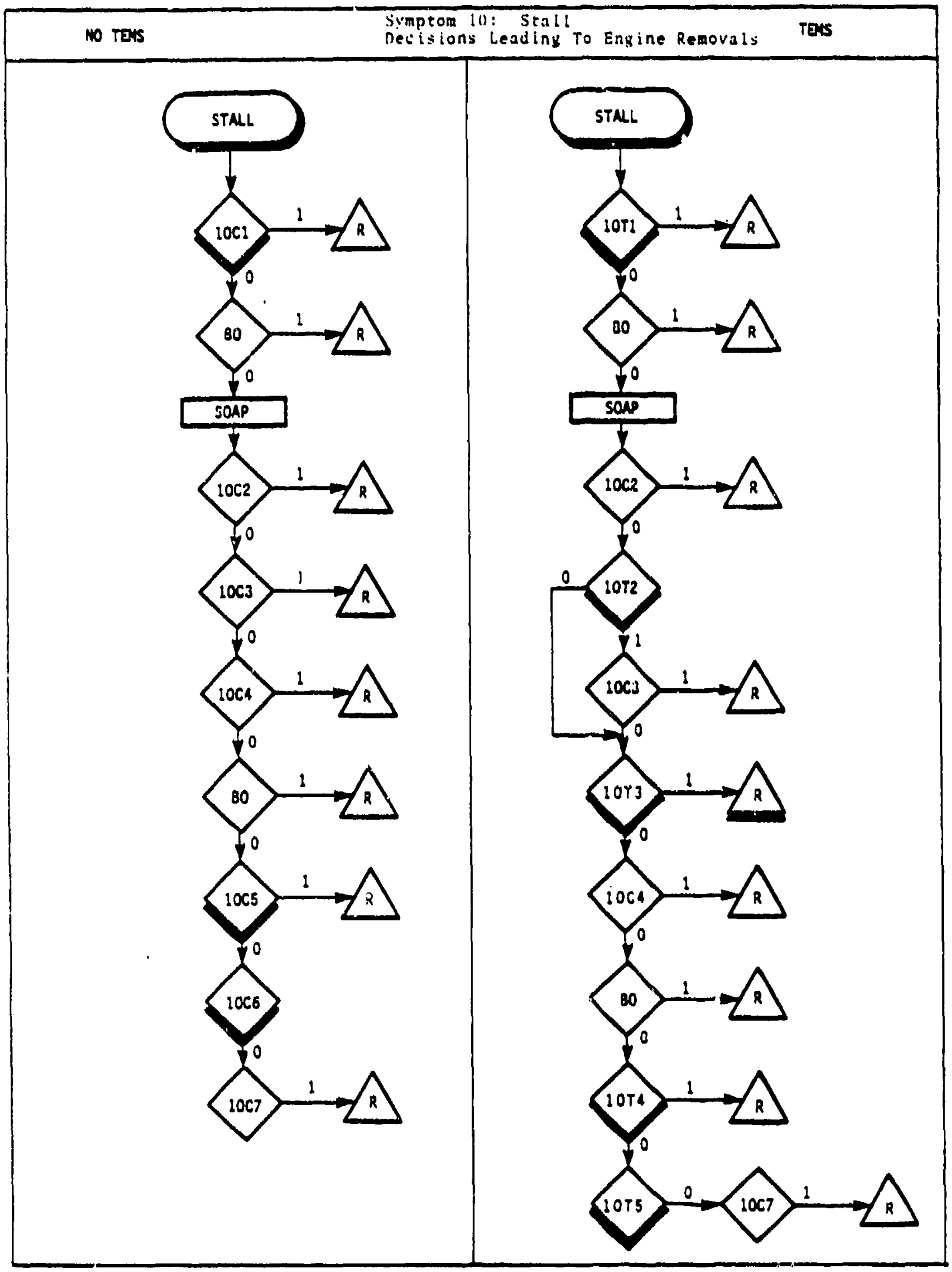


Figure 7.10 Symptom 10

Table 7.1

Key to Figures 7.3 Through 7.10

CODE TO DECISION DIAGRAM SYMBOLS		
SYMPTOM # FOR WHICH CHECK IS DONE (1, 1', 2, 4, 5, 7, 8, 10)	TYPE OF CHECK: SPECIALIST JUDGMENT (C) OR TEMS (T)	NUMERICAL IDENTIFIER 1, 2, 3

◇ : A DECISION

▭ : AN ACTION

△ : OUTCOME OF ENGINE REMOVAL OR REPLACEMENT

⬭ : INPUT OR SYMPTOM DETECTION

Undershaded blocks indicate differences between maintenance procedures with and without TEMS.

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
1C1	CHECK ITT READINGS	1: ITT EXCEEDS LIMITS 0: ITT DOES NOT EXCEED LIMITS
	ITT LIMITS (STARTING CYCLE):	1010°C, 2 SEC. 930°C, 5 SEC. 870°C, 25 SEC. 860°C, 50 SEC.
1C2	CHECK ITT READINGS RESULTS OF PREVIOUS START	1: ITT EXCEEDS LIMITS 0: ITT DOES NOT EXCEED LIMITS
1C3	CHECK ITT INDICATOR	1: BAD 0: OKAY
1C4	CHECK STARTING SYSTEM	1: BAD 0: OKAY
1C5	CHECK STATOR VANES	1: ARMS POPPED 0: OKAY
1C6	CHECK VG FEEDBACK CABLE	1: HUNG UP OR BOUND UP 0: TRAVELS FREELY
1C7	REMOVE & INSPECT LPT MODULE	1: BAD 0: OKAY

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
1'C1	CHECK ITT READINGS	3: ITT > 1000°C 2: 927 < ITT ≤ 1000°C 1: 830 < ITT ≤ 927°C 0: ITT ≤ 830°C
1'C2	CHECK Ng/ITT INDICATOR	1: BAD 0: OKAY
1'C3	CONTROL DISABLE CHECK	1: CHECK NOT OKAY 0: CHECK OKAY
1'C4	CHECK WHETHER Ng REACHES 99-100% BUT ITT & Ng REMAIN LOW	1: YES 0: NO
1'C5	CHECK VG FEEDBACK CABLE FOR SECURITY	1: NOT SECURE 0: SECURE
1'C6	CHECK VG FEEDBACK CABLE FOR BINDING	1: BOUND UP 0: OKAY
1'C7	DISCONNECT VG FEEDBACK CABLE AND SEE HOW MUCH FORCE REQUIRED TO MOVE IT	1: > 4LB. FORCE REQUIRED 0: ≤ 4LB. FORCE REQUIRED
1'C8	CHECK FUEL CONTROL FEEDBACK LEVER ARM	2: HUNG UP 1: BINDING 0: OKAY

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS

#	CHECK (INPUT TO DECISION)	DECISIONS
1'C9	CHECK CONTINUITY OF THERMOCOUPLE AND JUNCTION BOX	2: ITT OVERSHOOT IF DISCONNECT J3,J4 1: ITT OVERSHOOT IF DISCONNECT ONE OF 0: NO ITT OVERSHOOTS IF EITHER J3 OR J4 DISCONNECTED.
1'C10	CHECK CONTROL AMPLIFIER	1: BAD 0: OKAY
1'C11	CHECK TORQUE MOTOR WINDING CONTINUITY	1: BAD 0: OKAY
1'C12	CHECK IDLE SPEED	1: BELOW 55% 0: ABOVE 55%
2C1	CHECK Ng SPEED	2: 102-104.5%, > 2 SECS. 1: ABOVE 99.4%, BUT ABOVE 102% FOR < 2 SECS 0: LESS THAN 99.4%
2C2	CHECK Nf SPEED	2: ABOVE 100Δ OR ABOVE 99.7% FOR > 3 SEC. 99.7% TO 100% 1: 94.5% TO 99.7% OR 99.7% TO 100% FOR < 3 SEC. 0: LESS THAN 94.5%

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
4C1	INSPECT FOR LARGE OIL LEAKAGE	1: LARGE LEAKAGE 0: NO LARGE LEAKAGE
4C2	CHECK FOR HIGH OIL CONSUMPTION	1: HIGH CONSUMPTION FOUND 0: NO HIGH CONSUMPTION
4C3	CHECK OIL TEMP.	1: LOW 0: OK
4C4	CHECK OIL PRESSURE INDICATORS	1: BAD 0: OKAY
4C5	CHECK OIL FILTER	1: CHIPS 0: NO CHIPS
4C6	CHECK OIL LINES	1: LINES KINKED OR BLOCKED 0: LINES NOT KINKED OR BLOCKED
4C7	CHECK CHIP DETECTORS	1: CHIPS 0: NO CHIPS
5C1	CHECK VIBRATION INDICATOR SYSTEM	1: BAD 0: OKAY
5C2	CHECK ENGINE MOUNTS	1: BAD 0: OKAY
5C3	CHECK OIL PRESSURE	1: BAD 0: OKAY
5C4	RESULTS OF TROUBLESHOOTING CHIPS (SYMPTOM 8)	1: CHIPS (REJECT ENGINE) 0: INSUFFICIENT CHIPS TO REJECT
5C5	CHECK FOR ROTOR SPEED PROBLEM	1: PROBLEMS 0: NO PROBLEMS
5C6	CHECK FOR COMPRESSOR ROTOR IMBALANCE USING VIB SCAN	1: IMBALANCE DETECTED 0: OKAY

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
5C7	CHECK FAN DISK BRUSHING MOVEMENT	1: BAD 0: OKAY
5C8	INSPECT FAN AND LPT ROTOR	1: PROBLEMS 0: OKAY
5C9	CHECK FOR LPT ROTOR IMBALANCE	1: IMBALANCE DETECTED 0: NO IMBALANCE
5C10	CHECK FOR FAN ROTOR IMBALANCE	1: IMBALANCE DETECTED 0: NO IMBALANCE
7C1	CHECK AIRCRAFT IMPENDING BYPASS INDICATOR	1: ON 0: OFF
7C2	CHECK FUEL FILTER BYPASS BUTTON	1: BUTTON POPPED 0: BUTTON NOT POPPED
8C1	CHECK FOR CONTAMINATION ON PLUG	1: CHIPS ON PLUG 0: NORMAL FUZZ OR SMALL SLIVERS
8C2	INSPECT LUBE FILTER	1: DIRTY 0: CLEAN
8C3	DRAIN OIL TANK, CHECK FOR CONTAMINATION	1: CONTAMINATION IN ENTIRE SYSTEM 0: MINOR CONTAMINATION
10C1	PILOT REPORT (ENGINE OPERATED OUTSIDE OF NORMAL LIMITS?)	1: VIBRATION LIMITS EXCEEDED 0: LIMITS NOT EXCEEDED
10C2	INSPECT LUBE FILTER	1: HEAVY METAL CHIPS 0: NO CHIPS
10C3	INSPECT CHIP DETECTORS	1: HEAVY METAL CHIPS 0: NO CHIPS
10C4	CHECK FEEDBACK CABLE (FUEL CONTROL FEEDBACK LEVER ARM)	1: HUNG UP 0: NOT HUNG UP

Table 7.1 (Continued)

CHECKS/DECISIONS WITHOUT TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
10C5	CHECK STATOR SCHEDULE	1: > 4° OPEN AT 92% Ng. 0: ≤ 4° OPEN AT 92% Ng.
10C6	CHECK Ng	1: BAD 0: OKAY
10C7	STALL TEST RESULTS	1: STALL AFTER REPLACE MFC 0: NO STALL OR MFC NOT REPLACED

Table 7.1 (Continued)

CHECKS/DECISIONS WITH TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
1T1	DDU F1, G11, B4	1: ITT > 1000°C, > 2 SEC. 0: ITT NOT > 1000°C FOR > 2 SEC.
1T2	DDU F1, G10, B4	1: ITT > 927°C, > 5 SEC. 0: ITT NOT > 927°C FOR > 5 SEC.
1T3	DDU G8	1: INSUFFICIENT COOLDOWN BETWEEN STARTS 0: SUFFICIENT COOLDOWN
1'T1	DDU G-7 (WF OVERRIDE) PILOT	2: ON, PILOT DID NOT SELECT 1: ON, PILOT SELECTED 0: NOT ON
1'T2	DDU F1	2: LEVEL 2 1: LEVEL 1 0: NOT ON
1'T3	DDU G10, G11, B4	2: ITT > 1000°C 1: ITT BETWEEN 927°C & 1000°C 0: ITT < 927°C
1'T4	COMPARE DDU B1, B4, B5, C1 FROM LEFT AND RIGHT ENGINES	1: ALL AGREE EXCEPT B4 0: NOT OPTION 1
1'T5	DDU F10	1: STALL OCCURRED 0: NO STALL
2T1	DDU C1 (Ng)	2: 102-104.5%, > 2 SECS. 1: ABOVE 99.4%, BUT ABOVE 102% FOR < 2 SECS. 0: LESS THAN 99.4Δ
2T2	DDU C2 (Nf)	2: ABOVE 100% OR ABOVE 99.7% FOR > 3 SEC. 1: 94.5% TO 99.7% OR 99.7% TO 100% FOR < 3 SEC.
2C1=2T1	2C1, 2T1 DECISIONS	Y: YES, THEY'RE THE SAME N: NO, THEY'RE NOT

Table 7.1 (Continued)

CHECKS/DECISIONS WITH TEMS		
#	CHECK (INPUT TO DECISION)	DECISIONS
2C2=2T2	2C2, 2T2 DECISIONS	Y: YES, THEY'RE THE SAME N: NO, THEY'RE NOT
2T3	DDU F2	1: OVERSPEED 0: NO OVERSPEED
4T1	DDU F-8	1: LIGHT ON (CHIPS) 0: LIGHT NOT ON (NO CHIPS)
5T1	DDU F-5 (VIBRATIONS)	2: LEVEL 2 (VIBRATIONS) 1: LEVEL 1 0: NOT ON
5T2	DDU F-8 (CHIPS)	1: ON (CHIPS) 0: NOT ON (NO CHIPS)
5T3	DDU F-1, F-2 (OVERTEMP, OVERSPEED)	1: F-1 OR F-2 ON (OVERSPEED OR OVERTEMP) 0: NEITHER ON
5T4	DDU E3↔E8 (VIBRATION LEVELS)	1: DETECT COMPRESSOR ROTOR IMBALANCE 0: NO PROBLEM DETECTED
5T5	DDU F-2 (Nf OVERSPEED)	2: LEVEL 2 1: LEVEL 1 0: LIGHT NOT ON
10T1	DDU G-6 (SLATS/HIGH AOA)	1: OVER g's BUT AOA NOT TOO GREAT 0: NOT 1
10T2	DDU F-8	1: LIT (CHIPS) 0: NOT LIT (NO CHIPS)
10T3	DDU F-7	1: LIT (FUEL FILTER CONTAM.) 0: NOT LIT (NO CONTAM.)
10T4	DDU F-11, D-8	1: VG OUT OF LIMITS 0: VG NOT OUT OF LIMITS
10T5	DDU F-9	1: Ng OUT (LIT) 0: Ng OKAY (NOT LIT)

Table 7.1 (Concluded)

OTHER CHECKS		
#	CHECK (INPUT TO DECISION)	DECISIONS
BO	RESULTS OF BORESCOPE INSPECTION	1: BAD 0: OKAY
SOAP	RESULTS OF SOAP REPORTS	1: BAD(IMPENDING BEARING FAILURE) 0: OKAY

For each symptom, block diagrams for procedures without and with TEMS appear side by side. Blocks representing actions which differ depending on the presence of TEMS are undershaded to emphasize changes in procedure due to TEMS. Only eight TEMS detectable symptoms can possibly lead to an engine removal; therefore symptoms 3, 6, 9 and 11 do not appear in Figures 7.3 to 7.10.

To conclude this section, Table 7.2 provides a complete listing of TF34 repair or replacement actions. These include actions resulting from TEMS-detectable symptoms as well as other symptoms. Nearly all the actions can occur as a result of a TEMS-detectable symptom.

Table 7.2

List of Possible TF34 Repair/Replacement Maintenance Actions

REPLACE IGNITER PLUGS
REPLACE FAULTY COMPONENTS IN IGNITER CIRCUIT
REPLACE FAULTY IGNITION EXCITER
REFILL FUEL TANKS
ATTEMPT TO START ENGINE
BLEED AIR FROM SUPPLY LINES
ADJUST THROTTLE RIGGING (OR RERIG THROTTLE)
ADJUST STARTER AIR PRESSURE
REPAIR OVERBOARD DRAINS (TIGHTEN FITTINGS OR REPLACE DEFECTIVE COMPONENT)
REPLACE FUEL PUMP
REPLACE FUEL CONTROL
REMOVE ENGINE (REPLACE PTO)
RERIG PLA (POWER LEVER ANGLE)
DISCONNECT/RECONNECT PRIMER VALUE INLET HOSE
MAKE WET ROLLOVER (PURGE FUEL FROM ENGINE)
REPLACE TACH GENERATOR
REPLACE NG INDICATOR OR HARNESS
REPLACE STARTER
REPLACE STARTER CUTOUT SPEED SWITCH
REPLACE STARTER AIR SHUTOFF VALVE (ALSO TIGHTEN CONNECTOR OR REPLACE LEAD)
REPAIR POWER SUPPLY (REF. STARTER AIR VALVE SOLENOID) OR CORRECT INPUT POWER SUPPLY
REPLACE START SWITCH
REPLACE RADIAL DRIVE SHAFT (REF. GAS GENERATOR)
REPLACE ENGINE
REPLACE ENGINE (FOD REPAIR)

Table 7.2 (Continued)

REPLACE T5 INDICATOR
ADJUST VG SCHEDULE
RECONNECT TURNBUCKLES BETWEEN UNION RINGS AND ACTUATOR SHAFT
RECONNECT ACTUATORS TO TORQUE SHAFTS
RETURN ENGINE TO ASSEMBLY
RERIG FEEDBACK CABLE
REPLACE FEEDBACK CABLE
REMOVE AND REPAIR COMPRESSOR
REMOVE AND REPAIR HPT TURBINE
REMOVE LPT MODULE AND INSPECT
REMOVE ENGINE AND REPAIR DEFECTIVE LPT MODULE
REPLACE T_2 SENSOR
CORRECT COMPRESSOR BLEED AIR LEAKAGE
REPLACE FUEL DISTRIBUTOR
REPLACE CIT SENSOR
TIGHTEN OR REPLACE P3 SENSING LINES
REPLACE OR RECALIBRATE IDLE SPEED INDICATOR
ADJUST IDLE SPEED SETTING ON FUEL CONTROL
REMOVE FUEL CONTROL AND REPLACE FUEL PUMP TO CONTROL DRIVE SHAFT
DRAIN AND REFILL FUEL SYSTEM
REPLACE FAULTY FAN COMPONENT (INDICATOR, SPEED SENSOR, RED ELECTRICAL CABLE)
MELT ICE WITH PORTABLE HEATERS
REPLACE ETTR
REPAIR/REPLACE POWER LEVER LINKAGE

Table 7.2 (Continued)

TIGHTEN OR REPLACE COMPRESSOR DISCHARGE PRESSURE SYSTEM LINES
REPLACE CONTROL AMPLIFIER
REDUCE BLEED OR POWER EXTRACTION
REPAIR/REPLACE TERMOCOUPLE OR WHITE HARNESS (T5 ELECTRICAL SYSTEM)
REPAIR/REPLACE P3 TUBE OR ACCUMULATOR
CONNECT/TIGHTEN OR REPLACE BLACK HARNESS OF MFC (CONNECTS TO MFC ROTARY RATE TRANSDUCER)
REPAIR HARNESS OR SWITCH (IN AIRFRAME WIRING)
REPLACE DENTED TUBING/FAULTY HOSES
REPLACE OIL COOLER CHECK VALVE
REPLACE T5 AMPLIFIER
REMOVE ENGINE AND REPLACE STAGE COMPRESSOR ROTOR BLADES
REMOVE AND INSPECT FUEL FILTER AND CHIP DETECTORS
REPLACE FUEL FILTER
CONDUCT 30 MINUTE GROUND RUN
ADD OIL TO TANK
REPLACE OIL SUPPLY LINES OR FITTINGS
REPLACE C-SUMP COVER OR COVER PACKINGS
REPLACE PACKINGS IN OIL FILL CAP
REPLACE ALL OR FAULTY COMPONENTS IN OIL PRESSURE INDICATOR
REPLACE OIL TANK PRESSURIZING VALVE
REPLACE OIL COOLER
CLEAN/REPLACE LUBE FILTER
PERFORM JOAP CHECK
BORESCOPE ENGINE

Table 7.2 (Concluded)

CLEAN/REPLACE OIL PUMP RELIEF VALVE
INSTALL LUBE FILTER CHECK VALVE CORRECTLY
REPLACE/TIGHTEN TRANSMITTER, PUMP, COMBUSTION, OR B-SUMP SCAVENGE LINE
REPLACE OIL PRESSURE TRANSMITTER
REPLACE OIL PUMP-TACH PAD SEAL OR REPLACE PUMP
REPLACE LUBE PUMP
REPLACE A-SUMP OR INTERSHAFT LABRYINTH OR NO. 7 CARBON SEAL
REPAIR ACCESSORY GEARBOX
BRAZE REPAIR ON TUBES INSIDE EXHAUST FRAME
RUN ENGINE AT IDLE WITH CENTERBODY REMOVED (FACILITATES LEAK CHECK)
REPLACE AIR PRESSURE REGULATOR VALVE
REPAIR C-SUMP (SCAVENGE REPLACE LINES, REPAIR LEAKS)
REPAIR VIBRATION SYSTEM INDICATOR
RESEAT FAN BLADE BUSHINGS (SEC. V)
REPLACE LOW PRESSURE TURBINE ROTOR (LPT)
REALIGN/TIGHTEN ENGINE MOUNTS
REPLACE FAN ROTOR
CORRECT FUEL SYSTEM HOSE ROUTING
REPLACE FUEL DISTRIBUTOR
REPLACE N_F PICKUP

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